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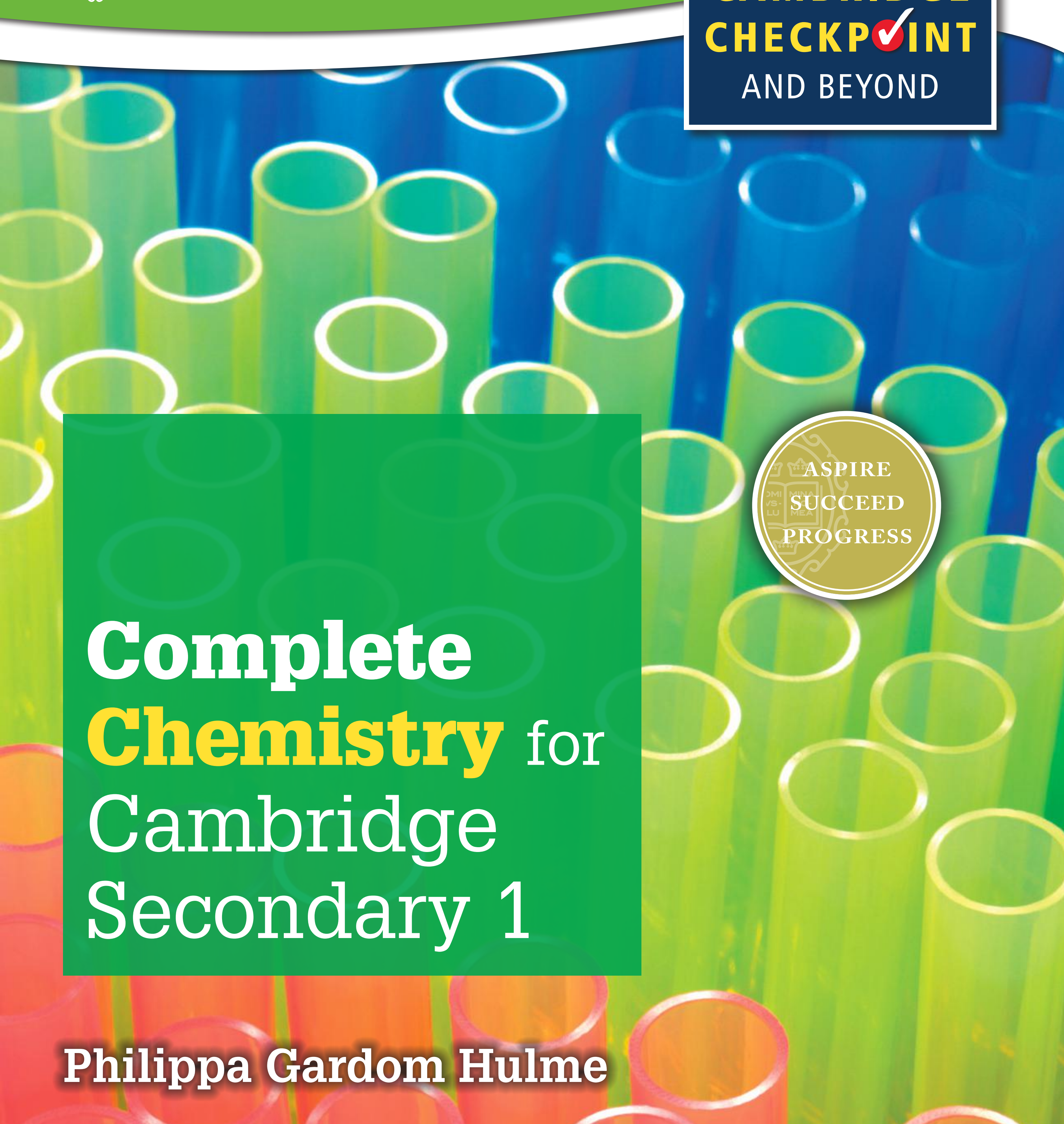

Complete Chemistry for Cambridge Secondary 1

Philippa Gardom Hulme

Oxford excellence for Cambridge Secondary 1

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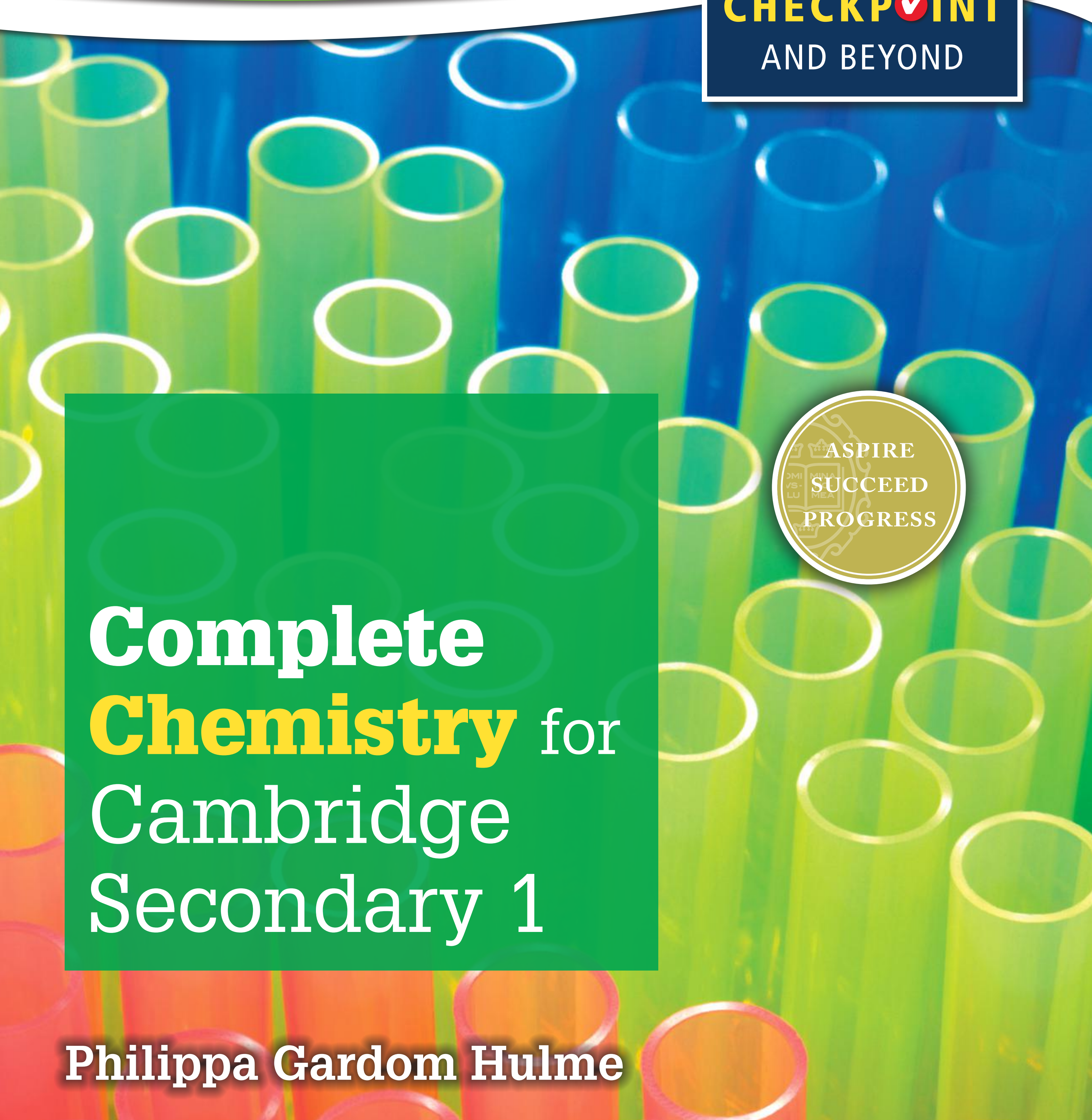

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Complete Chemistry for Cambridge Secondary 1

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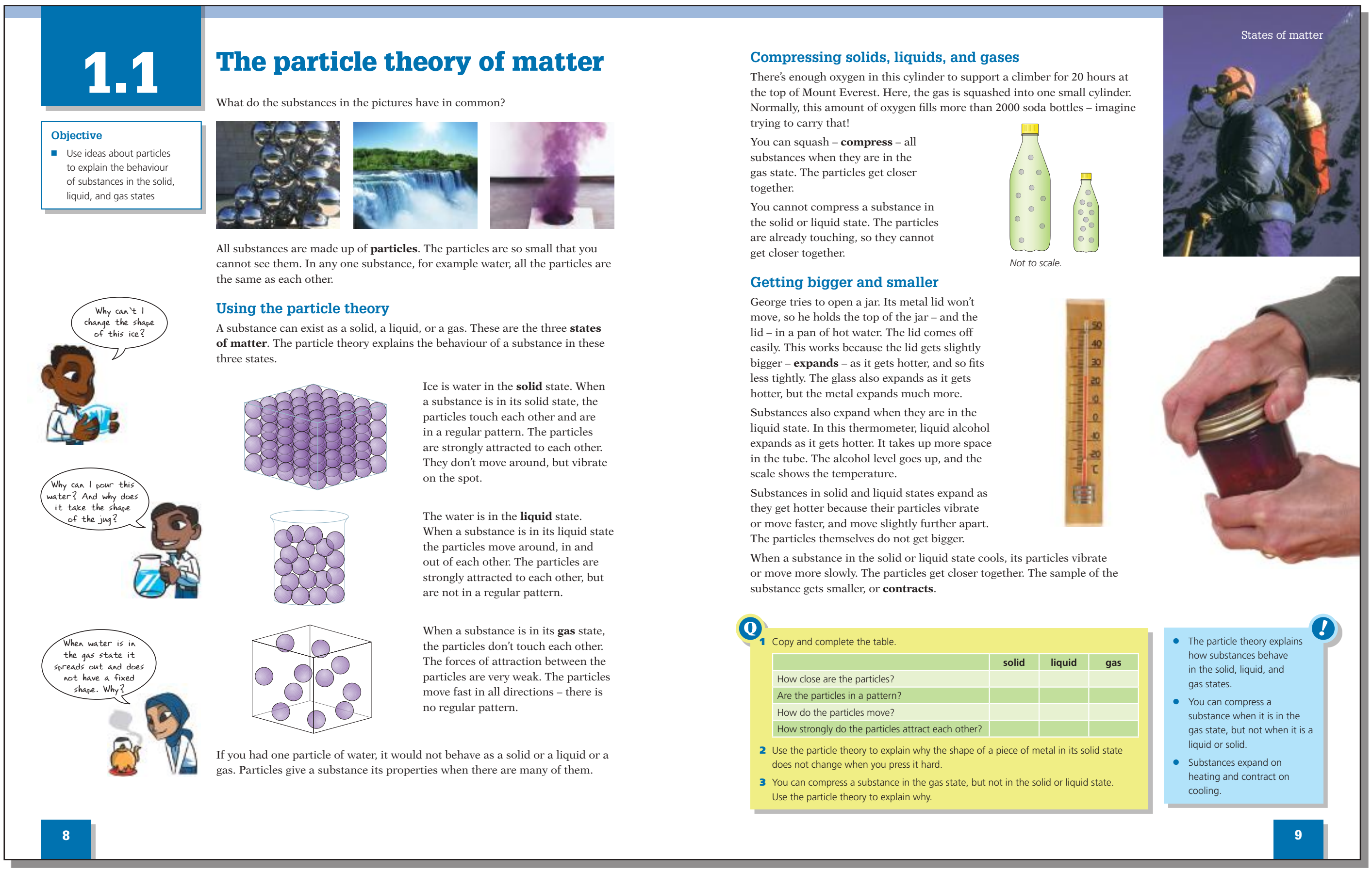
Contents

Stage 9

How to use your Student Book

Welcome to your **Complete Chemistry for Cambridge Secondary 1** Student Book. This book has been written to help you study Chemistry at all three stages of Cambridge Secondary 1.

Most of the pages in this book work like this:



1.1

The particle theory of matter

What do the substances in the pictures have in common?

Objective

- Use ideas about particles to explain the behaviour of substances in the solid, liquid, and gas states

All substances are made up of **particles**. The particles are so small that you cannot see them. In any one substance, for example water, all the particles are the same as each other.

Using the particle theory

A substance can exist as a solid, a liquid, or a gas. These are the three **states of matter**. The particle theory explains the behaviour of a substance in these three states.

Why can't I change the shape of this ice?

Ice is water in the **solid** state. When a substance is in its solid state, the particles touch each other and are in a regular pattern. The particles are strongly attracted to each other. They don't move around, but vibrate on the spot.

Why can I pour this water? And why does it take the shape of the jug?

The water is in the **liquid** state. When a substance is in its liquid state the particles move around, in and out of each other. The particles are strongly attracted to each other, but are not in a regular pattern.

When water is in the gas state it spreads out and does not have a fixed shape. Why?

When a substance is in its **gas** state, the particles don't touch each other. The forces of attraction between the particles are very weak. The particles move fast in all directions – there is no regular pattern.

If you had one particle of water, it would not behave as a solid or a liquid or a gas. Particles give a substance its properties when there are many of them.

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States of matter

Compressing solids, liquids, and gases

There's enough oxygen in this cylinder to support a climber for 20 hours at the top of Mount Everest. Here, the gas is squashed into one small cylinder. Normally, this amount of oxygen fills more than 2000 soda bottles – imagine trying to carry that!

You can squash – **compress** – all substances when they are in the gas state. The particles get closer together.

You cannot compress a substance in the solid or liquid state. The particles are already touching, so they cannot get closer together.

Not to scale.

Getting bigger and smaller

George tries to open a jar. Its metal lid won't move, so he holds the top of the jar – and the lid – in a pan of hot water. The lid comes off easily. This works because the lid gets slightly bigger – **expands** – as it gets hotter, and so fits less tightly. The glass also expands as it gets hotter, but the metal expands much more.

Substances also expand when they are in the liquid state. In this thermometer, liquid alcohol expands as it gets hotter. It takes up more space in the tube. The alcohol level goes up, and the scale shows the temperature.

Substances in solid and liquid states expand as they get hotter because their particles vibrate or move faster, and move slightly further apart. The particles themselves do not get bigger.

When a substance in the solid or liquid state cools, its particles vibrate or move more slowly. The particles get closer together. The sample of the substance gets smaller, or **contracts**.

Q

1 Copy and complete the table.

	solid	liquid	gas
How close are the particles?			
Are the particles in a pattern?			
How do the particles move?			
How strongly do the particles attract each other?			

2 Use the particle theory to explain why the shape of a piece of metal in its solid state does not change when you press it hard.

3 You can compress a substance in the gas state, but not in the solid or liquid state. Use the particle theory to explain why.

!

- The particle theory explains how substances behave in the solid, liquid, and gas states.
- You can compress a substance when it is in the gas state, but not when it is a liquid or solid.
- Substances expand on heating and contract on cooling.

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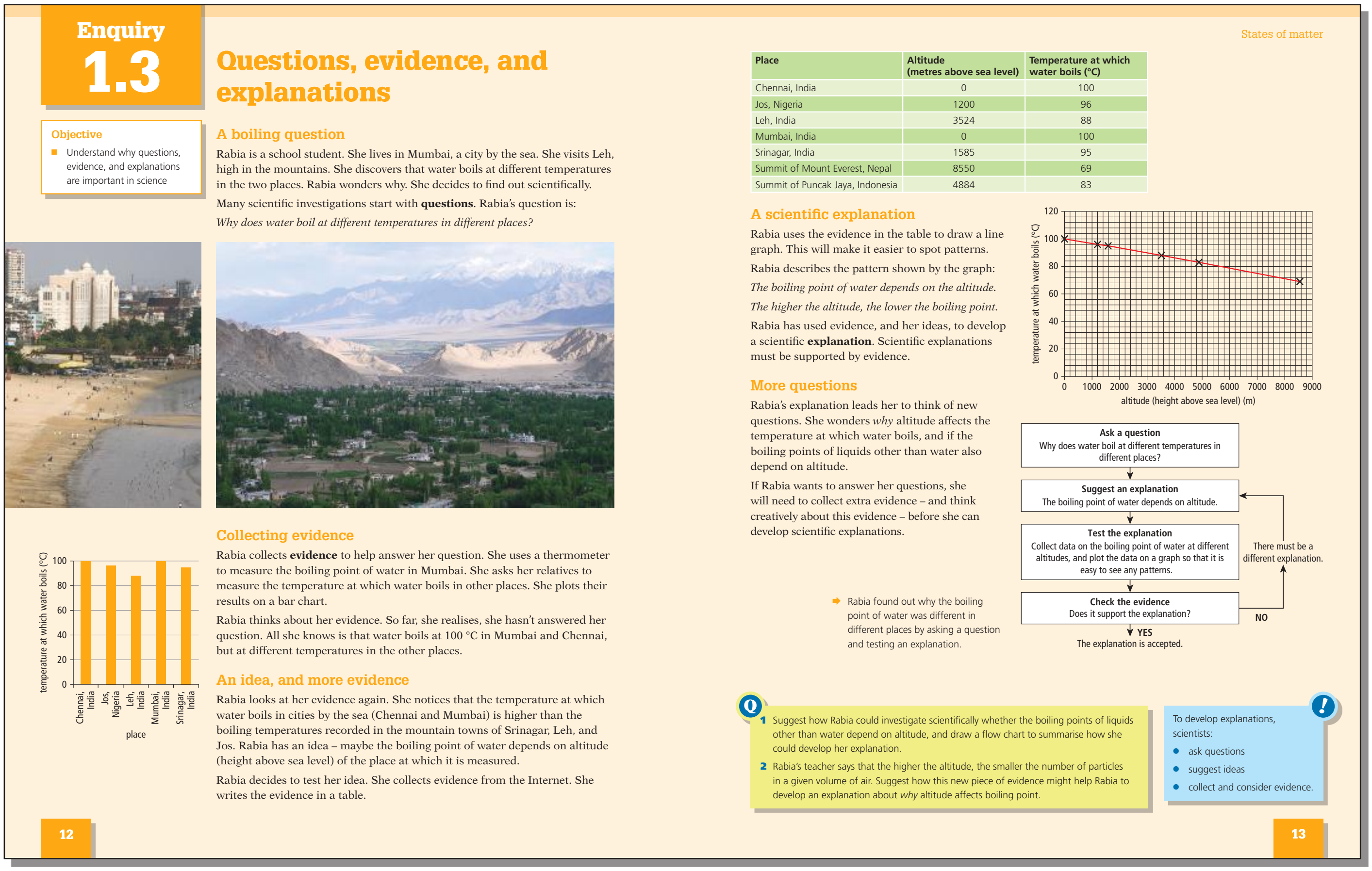
- Every page starts with the learning objectives for the lesson. The learning objectives match the Cambridge Secondary 1 Science curriculum framework.
- New vocabulary is marked in bold. You can check the meaning of these words in the glossary at the back of the book.
- At the end of each page there are questions to test that you understand what you have learned.
- The key points to remember from the page are also summarised here.

These pages cover the Chemistry topics in the Cambridge Secondary 1 Science curriculum framework. In addition, in every chapter there are also pages that help you think like a scientist, prepare for the next level, and test your knowledge. Find out more on the next page.

Scientific enquiry

These pages help you to practise the skills that you need to be a good scientist. They cover all the scientific enquiry learning objectives from the curriculum framework.



Enquiry 1.3

Questions, evidence, and explanations

Objective
- Understand why questions, evidence, and explanations are important in science

A boiling question

Rabia is a school student. She lives in Mumbai, a city by the sea. She visits Leh, high in the mountains. She discovers that water boils at different temperatures in the two places. Rabia wonders why. She decides to find out scientifically.

Many scientific investigations start with **questions**. Rabia's question is:

Why does water boil at different temperatures in different places?

Collecting evidence

Rabia collects **evidence** to help answer her question. She uses a thermometer to measure the boiling point of water in Mumbai. She asks her relatives to measure the temperature at which water boils in other places. She plots their results on a bar chart.

Rabia thinks about her evidence. So far, she realises, she hasn't answered her question. All she knows is that water boils at 100 °C in Mumbai and Chennai, but at different temperatures in the other places.

An idea, and more evidence

Rabia looks at her evidence again. She notices that the temperature at which water boils in cities by the sea (Chennai and Mumbai) is higher than the boiling temperatures recorded in the mountain towns of Srinagar, Leh, and Jos. Rabia has an idea – maybe the boiling point of water depends on altitude (height above sea level) of the place at which it is measured.

Rabia decides to test her idea. She collects evidence from the Internet. She writes the evidence in a table.

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States of matter

Place	Altitude (metres above sea level)	Temperature at which water boils (°C)
Chennai, India	0	100
Jos, Nigeria	1200	96
Leh, India	3524	88
Mumbai, India	0	100
Srinagar, India	1585	95
Summit of Mount Everest, Nepal	8550	69
Summit of Puncak Jaya, Indonesia	4884	83

A scientific explanation

Rabia uses the evidence in the table to draw a line graph. This will make it easier to spot patterns.

Rabia describes the pattern shown by the graph:

The boiling point of water depends on the altitude.

The higher the altitude, the lower the boiling point.

Rabia has used evidence, and her ideas, to develop a scientific **explanation**. Scientific explanations must be supported by evidence.

More questions

Rabia's explanation leads her to think of new questions. She wonders *why* altitude affects the temperature at which water boils, and if the boiling points of liquids other than water also depend on altitude.

If Rabia wants to answer her questions, she will need to collect extra evidence – and think creatively about this evidence – before she can develop scientific explanations.

➡ Rabia found out why the boiling point of water was different in different places by asking a question and testing an explanation.

Q

1. Suggest how Rabia could investigate scientifically whether the boiling points of liquids other than water depend on altitude, and draw a flow chart to summarise how she could develop her explanation.
2. Rabia's teacher says that the higher the altitude, the smaller the number of particles in a given volume of air. Suggest how this new piece of evidence might help Rabia to develop an explanation about *why* altitude affects boiling point.

!

To develop explanations, scientists:
- ask questions
- suggest ideas
- collect and consider evidence.

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You will learn how to:

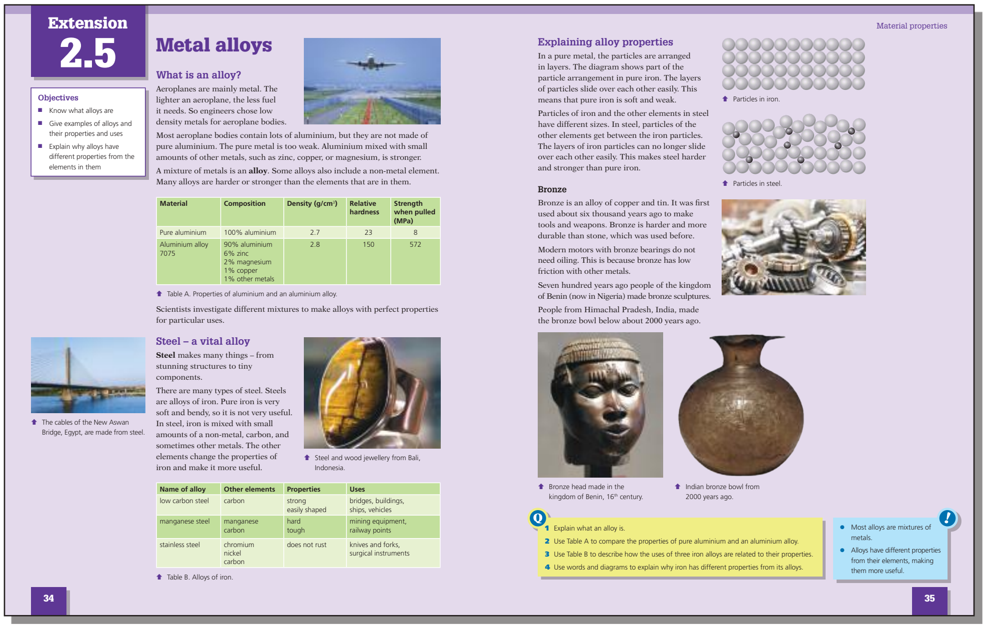
- consider ideas
- plan investigations and experiments
- record and analyse data
- evaluate evidence to draw scientific conclusions.

You will also learn how scientists throughout history and from around the globe created theories, carried out research, and drew conclusions about the world around them.

Extension

Throughout this book there are lots of opportunities to learn even more about chemistry beyond the Cambridge Secondary 1 Science curriculum framework. These topics are called *Extension* because they extend and develop your science skills even further.

You can tell when a topic is extension because it is marked with a dashed line, like the one on the left. Or when the page has a purple background, like below.



Extension 2.5

Metal alloys

Objectives
- Know what alloys are
- Give examples of alloys and their properties and uses
- Explain why alloys have different properties from the elements in them

What is an alloy?

Aeroplanes are mainly metal. The lighter an aeroplane, the less fuel it needs. So engineers chose low density metals for aeroplane bodies.

Most aeroplane bodies contain lots of aluminium, but they are not made of pure aluminium. The pure metal is too weak. Aluminium mixed with small amounts of other metals, such as zinc, copper, or magnesium, is stronger.

A mixture of metals is an **alloy**. Some alloys also include a non-metal element. Many alloys are harder or stronger than the elements that are in them.

Material	Composition	Density (g/cm³)	Relative hardness	Strength when pulled (MPa)
Pure aluminium	100% aluminium	2.7	23	8
Aluminium alloy 7075	90% aluminium 6% zinc 2% magnesium 1% copper 1% other metals	2.8	150	572

Table A. Properties of aluminium and an aluminium alloy.

Scientists investigate different mixtures to make alloys with perfect properties for particular uses.

Steel – a vital alloy

Steel makes many things – from stunning structures to tiny components.

There are many types of steel. Steels are alloys of iron. Pure iron is very soft and bendy, so it is not very useful. In steel, iron is mixed with small amounts of a non-metal, carbon, and sometimes other metals. The other elements change the properties of iron and make it more useful.

The cables of the New Aswan Bridge, Egypt, are made from steel.

Steel and wood jewellery from Bali, Indonesia.

Name of alloy	Other elements	Properties	Uses
low carbon steel	carbon	strong easily shaped	bridges, buildings, ships, vehicles
manganese steel	manganese carbon	hard tough	mining equipment, railway points
stainless steel	chromium nickel carbon	does not rust	knives and forks, surgical instruments

Table B. Alloys of iron.

Material properties

Explaining alloy properties

In a pure metal, the particles are arranged in layers. The diagram shows part of the particle arrangement in pure iron. The layers of particles slide over each other easily. This means that pure iron is soft and weak.

Particles of iron and the other elements in steel have different sizes. In steel, particles of the other elements get between the iron particles. The layers of iron particles can no longer slide over each other easily. This makes steel harder and stronger than pure iron.

Particles in iron.

Particles in steel.

Bronze

Bronze is an alloy of copper and tin. It was first used about six thousand years ago to make tools and weapons. Bronze is harder and more durable than stone, which was used before.

Modern motors with bronze bearings do not need oiling. This is because bronze has low friction with other metals.

Seven hundred years ago people of the kingdom of Benin (now in Nigeria) made bronze sculptures.

People from Himachal Pradesh, India, made the bronze bowl below about 2000 years ago.

Bronze head made in the kingdom of Benin, 16th century.

Indian bronze bowl from 2000 years ago.

1 Explain what an alloy is.
2 Use Table A to compare the properties of pure aluminium and an aluminium alloy.
3 Use Table B to describe how the uses of three iron alloys are related to their properties.
4 Use words and diagrams to explain why iron has different properties from its alloys.

- Most alloys are mixtures of metals.
- Alloys have different properties from their elements, making them more useful.

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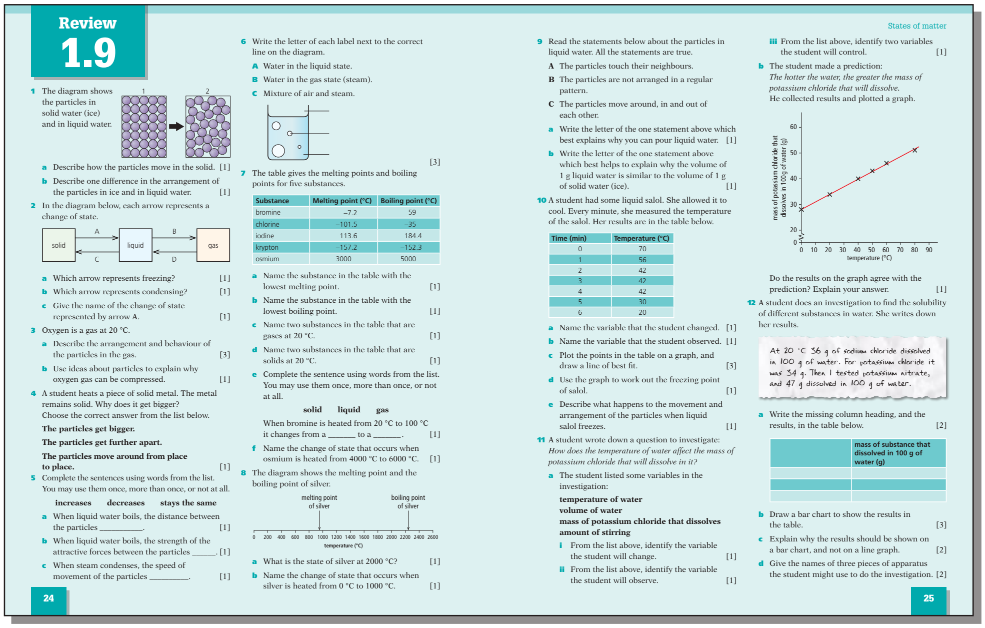
Extension topics will not be in your Cambridge Checkpoint test, but they will help you prepare for moving onto the next stage of the curriculum and eventually for Cambridge IGCSE® Chemistry.

Review

At the end of every chapter and every stage there are review questions.



Review 1.9

States of matter

1 The diagram shows the particles in solid water (ice) and in liquid water.
a Describe how the particles move in the solid. [1]
b Describe one difference in the arrangement of the particles in ice and in liquid water. [1]

2 In the diagram below, each arrow represents a change of state.
a Which arrow represents freezing? [1]
b Which arrow represents condensing? [1]
c Give the name of the change of state represented by arrow A. [1]

3 Oxygen is a gas at 20 °C.
a Describe the arrangement and behaviour of the particles in the gas. [3]
b Use ideas about particles to explain why oxygen gas can be compressed. [1]

4 A student heats a piece of solid metal. The metal remains solid. Why does it get bigger? Choose the correct answer from the list below.
The particles get bigger.
The particles get further apart.
The particles move around from place to place. [1]

5 Complete the sentences using words from the list. You may use them once, more than once, or not at all.
increases decreases stays the same
a When liquid water boils, the distance between the particles ________. [1]
b When liquid water boils, the strength of the attractive forces between the particles ________. [1]
c When steam condenses, the speed of movement of the particles ________. [1]

6 Write the letter of each label next to the correct line on the diagram.
A Water in the liquid state.
B Water in the gas state (steam).
C Mixture of air and steam. [3]

7 The table gives the melting points and boiling points for five substances.

Substance	Melting point (°C)	Boiling point (°C)
bromine	−7.2	59
chlorine	−101.5	−35
iodine	113.6	184.4
krypton	−157.2	−152.3
osmium	3000	5000

a Name the substance in the table with the lowest melting point. [1]
b Name the substance in the table with the lowest boiling point. [1]
c Name two substances in the table that are gases at 20 °C. [1]
d Name two substances in the table that are solids at 20 °C. [1]
e Complete the sentence using words from the list. You may use them once, more than once, or not at all.
solid liquid gas
When bromine is heated from 20 °C to 100 °C it changes from a ______ to a ______. [1]
f Name the change of state that occurs when osmium is heated from 4000 °C to 6000 °C. [1]

8 The diagram shows the melting point and the boiling point of silver.
a What is the state of silver at 2000 °C? [1]
b Name the change of state that occurs when silver is heated from 0 °C to 1000 °C. [1]

9 Read the statements below about the particles in liquid water. All the statements are true.
A The particles touch their neighbours.
B The particles are not arranged in a regular pattern.
C The particles move around, in and out of each other.
a Write the letter of the one statement above which best explains why you can pour liquid water. [1]
b Write the letter of the one statement above which best helps to explain why the volume of 1 g liquid water is similar to the volume of 1 g of solid water (ice). [1]

10 A student had some liquid salol. She allowed it to cool. Every minute, she measured the temperature of the salol. Her results are in the table below.

Time (min)	Temperature (°C)
0	70
1	56
2	42
3	42
4	42
5	30
6	20

a Name the variable that the student changed. [1]
b Name the variable that the student observed. [1]
c Plot the points in the table on a graph, and draw a line of best fit. [3]
d Use the graph to work out the freezing point of salol. [1]
e Describe what happens to the movement and arrangement of the particles when liquid salol freezes. [1]

11 A student wrote down a question to investigate: *How does the temperature of water affect the mass of potassium chloride that will dissolve in it?*
a The student listed some variables in the investigation:
temperature of water
volume of water
mass of potassium chloride that dissolves
amount of stirring
i From the list above, identify the variable the student will change. [1]
ii From the list above, identify the variable the student will observe. [1]
iii From the list above, identify two variables the student will control. [1]
b The student made a prediction: *The hotter the water, the greater the mass of potassium chloride that will dissolve.* He collected results and plotted a graph.

Do the results on the graph agree with the prediction? Explain your answer. [1]

12 A student does an investigation to find the solubility of different substances in water. She writes down her results.

At 20 °C 36 g of sodium chloride dissolved in 100 g of water. For potassium chloride it was 34 g. Then I tested potassium nitrate, and 47 g dissolved in 100 g of water.

a Write the missing column heading, and the results, in the table below. [2]
b Draw a bar chart to show the results in the table. [3]
c Explain why the results should be shown on a bar chart, and not on a line graph. [2]
d Give the names of three pieces of apparatus the student might use to do the investigation. [2]

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These questions are written in the style of Cambridge Checkpoint test. They are there to help you review what you have learned in that chapter or stage.

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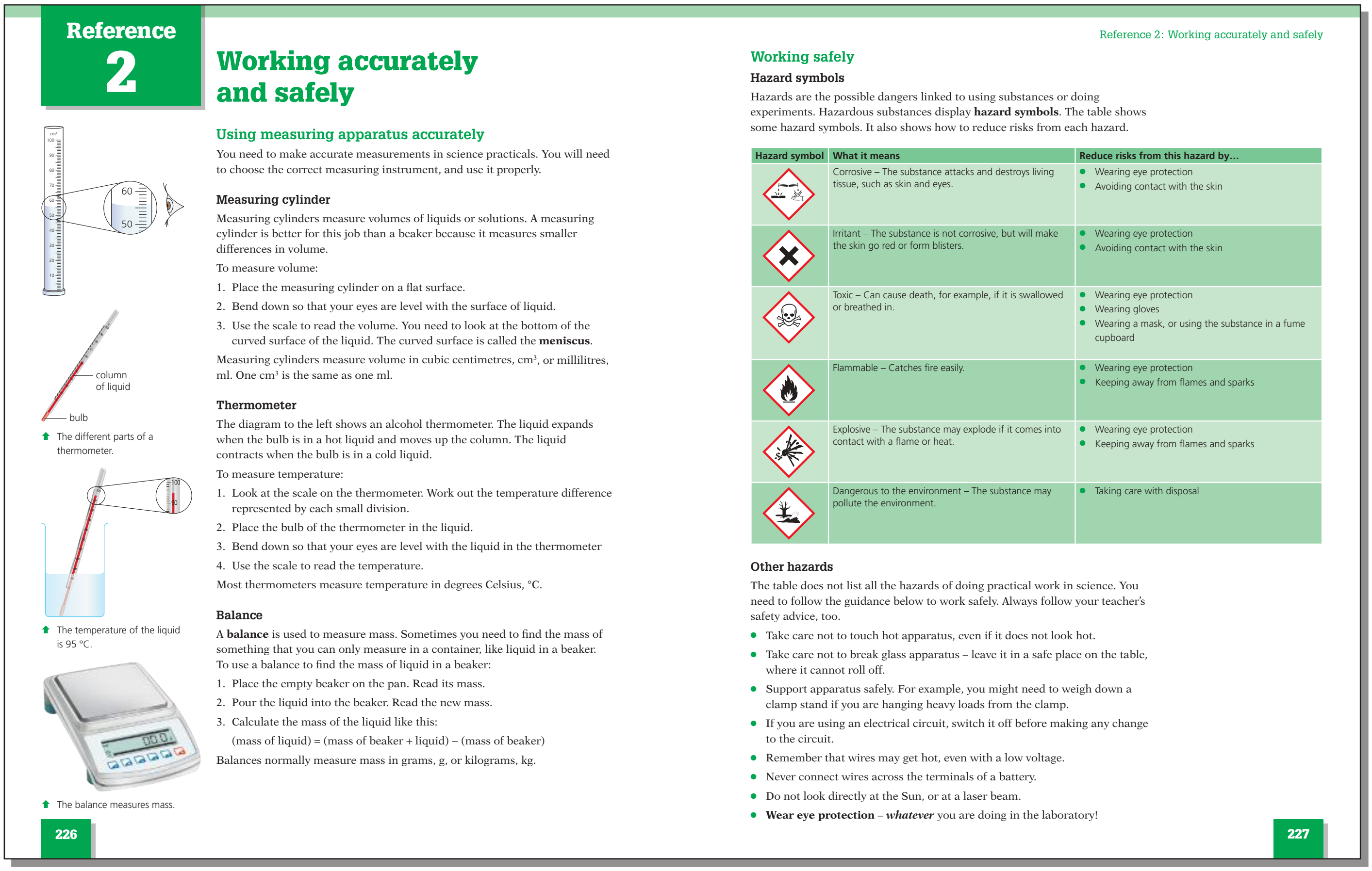
Reference

At the back of this book there are reference pages. These pages will be useful throughout every stage of Cambridge Secondary 1 Science.



Reference 2

Working accurately and safely

The different parts of a thermometer.

The temperature of the liquid is 95 °C.

The balance measures mass.

Using measuring apparatus accurately

You need to make accurate measurements in science practicals. You will need to choose the correct measuring instrument, and use it properly.

Measuring cylinder

Measuring cylinders measure volumes of liquids or solutions. A measuring cylinder is better for this job than a beaker because it measures smaller differences in volume.

To measure volume:

1. Place the measuring cylinder on a flat surface.
2. Bend down so that your eyes are level with the surface of liquid.
3. Use the scale to read the volume. You need to look at the bottom of the curved surface of the liquid. The curved surface is called the **meniscus**.

Measuring cylinders measure volume in cubic centimetres, cm^3, or millilitres, ml. One cm^3 is the same as one ml.

Thermometer

The diagram to the left shows an alcohol thermometer. The liquid expands when the bulb is in a hot liquid and moves up the column. The liquid contracts when the bulb is in a cold liquid.

To measure temperature:

1. Look at the scale on the thermometer. Work out the temperature difference represented by each small division.
2. Place the bulb of the thermometer in the liquid.
3. Bend down so that your eyes are level with the liquid in the thermometer
4. Use the scale to read the temperature.

Most thermometers measure temperature in degrees Celsius, °C.

Balance

A **balance** is used to measure mass. Sometimes you need to find the mass of something that you can only measure in a container, like liquid in a beaker. To use a balance to find the mass of liquid in a beaker:

1. Place the empty beaker on the pan. Read its mass.
2. Pour the liquid into the beaker. Read the new mass.
3. Calculate the mass of the liquid like this:
   (mass of liquid) = (mass of beaker + liquid) – (mass of beaker)

Balances normally measure mass in grams, g, or kilograms, kg.

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Reference 2: Working accurately and safely

Working safely

Hazard symbols

Hazards are the possible dangers linked to using substances or doing experiments. Hazardous substances display **hazard symbols**. The table shows some hazard symbols. It also shows how to reduce risks from each hazard.

Hazard symbol	What it means	Reduce risks from this hazard by…
	Corrosive – The substance attacks and destroys living tissue, such as skin and eyes.	• Wearing eye protection • Avoiding contact with the skin
	Irritant – The substance is not corrosive, but will make the skin go red or form blisters.	• Wearing eye protection • Avoiding contact with the skin
	Toxic – Can cause death, for example, if it is swallowed or breathed in.	• Wearing eye protection • Wearing gloves • Wearing a mask, or using the substance in a fume cupboard
	Flammable – Catches fire easily.	• Wearing eye protection • Keeping away from flames and sparks
	Explosive – The substance may explode if it comes into contact with a flame or heat.	• Wearing eye protection • Keeping away from flames and sparks
	Dangerous to the environment – The substance may pollute the environment.	• Taking care with disposal

Other hazards

The table does not list all the hazards of doing practical work in science. You need to follow the guidance below to work safely. Always follow your teacher's safety advice, too.

- Take care not to touch hot apparatus, even if it does not look hot.
- Take care not to break glass apparatus – leave it in a safe place on the table, where it cannot roll off.
- Support apparatus safely. For example, you might need to weigh down a clamp stand if you are hanging heavy loads from the clamp.
- If you are using an electrical circuit, switch it off before making any change to the circuit.
- Remember that wires may get hot, even with a low voltage.
- Never connect wires across the terminals of a battery.
- Do not look directly at the Sun, or at a laser beam.
- **Wear eye protection** – ***whatever*** you are doing in the laboratory!

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They include information on:

- how to choose suitable apparatus
- how to work accurately and safely
- how to detect gases
- how to record, display, and analyse results
- and a periodic table.

1.1 The particle theory of matter

Objective

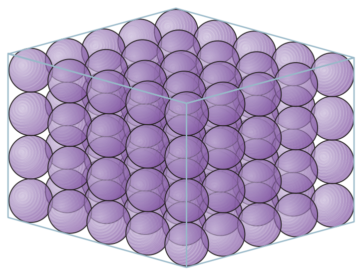
- Use ideas about particles to explain the behaviour of substances in the solid, liquid, and gas states

What do the substances in the pictures have in common?

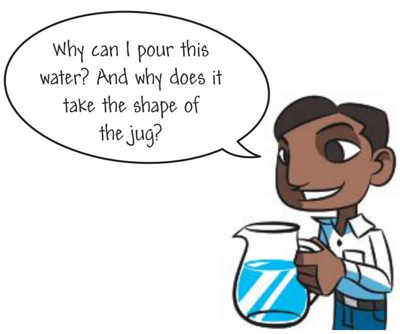
All substances are made up of **particles**. The particles are so small that you cannot see them. In any one substance, for example water, all the particles are the same as each other.

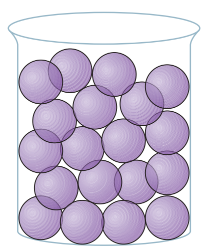
Using the particle theory

A substance can exist as a solid, a liquid, or a gas. These are the three **states of matter**. The particle theory explains the behaviour of a substance in these three states.

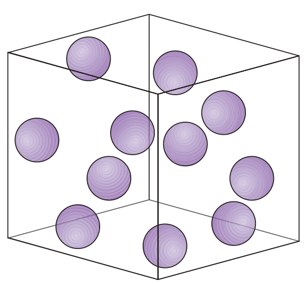


Ice is water in the **solid** state. When a substance is in its solid state, the particles touch each other and are in a regular pattern. The particles are strongly attracted to each other. They don't move around, but vibrate on the spot.



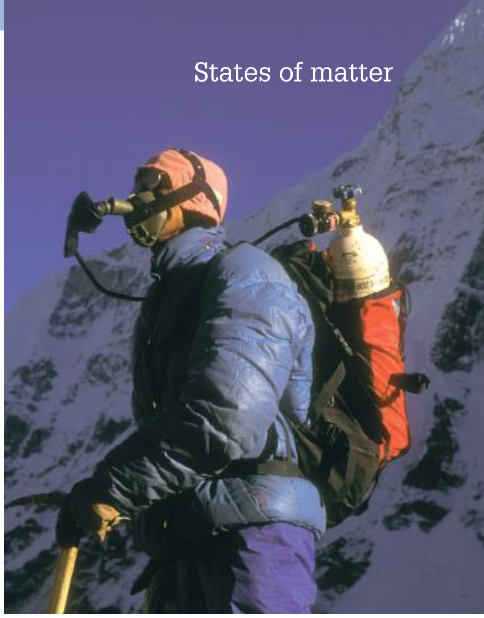


The water is in the **liquid** state. When a substance is in its liquid state the particles move around, in and out of each other. The particles are strongly attracted to each other, but are not in a regular pattern.



When a substance is in its **gas** state, the particles don't touch each other. The forces of attraction between the particles are very weak. The particles move fast in all directions – there is no regular pattern.

If you had one particle of water, it would not behave as a solid or a liquid or a gas. Particles give a substance its properties when there are many of them.

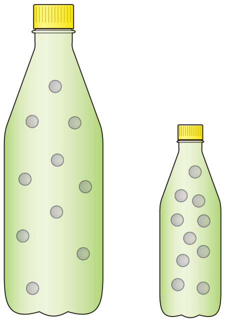


Compressing solids, liquids, and gases

There's enough oxygen in this cylinder to support a climber for 20 hours at the top of Mount Everest. Here, the gas is squashed into one small cylinder. Normally, this amount of oxygen fills more than 2000 soda bottles – imagine trying to carry that!

You can squash – **compress** – all substances when they are in the gas state. The particles get closer together.

You cannot compress a substance in the solid or liquid state. The particles are already touching, so they cannot get closer together.



Not to scale.

Getting bigger and smaller

George tries to open a jar. Its metal lid won't move, so he holds the top of the jar – and the lid – in a pan of hot water. The lid comes off easily. This works because the lid gets slightly bigger – **expands** – as it gets hotter, and so fits less tightly. The glass also expands as it gets hotter, but the metal expands much more.

Substances also expand when they are in the liquid state. In this thermometer, liquid alcohol expands as it gets hotter. It takes up more space in the tube. The alcohol level goes up, and the scale shows the temperature.

Substances in solid and liquid states expand as they get hotter because their particles vibrate or move faster, and move slightly further apart. The particles themselves do not get bigger.

When a substance in the solid or liquid state cools, its particles vibrate or move more slowly. The particles get closer together. The sample of the substance gets smaller, or **contracts**.

Q

1 Copy and complete the table.

	solid	liquid	gas
How close are the particles?			
Are the particles in a pattern?			
How do the particles move?			
How strongly do the particles attract each other?			

2 Use the particle theory to explain why the shape of a piece of metal in its solid state does not change when you press it hard.

3 You can compress a substance in the gas state, but not in the solid or liquid state. Use the particle theory to explain why.

!

- The particle theory explains how substances behave in the solid, liquid, and gas states.
- You can compress a substance when it is in the gas state, but not when it is a liquid or solid.
- Substances expand on heating and contract on cooling.

1.2 Boiling, evaporating, and condensing

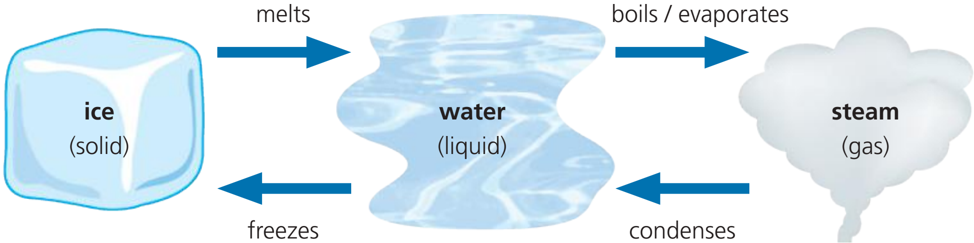
Objectives

- Name the changes of state involving liquids and gases
- Explain changes of state using ideas about particles

Changing state

Chahaya lights a candle. Some of the solid wax changes to the liquid state. Some of the liquid wax becomes wax gas. The wax gas burns.

When a substance changes from one state to another, its particles don't change. All that changes is the distance between the particles, their speed, and the attraction between them.



Melting, boiling, evaporating, condensing, and freezing are all **changes of state**.

Liquid to gas

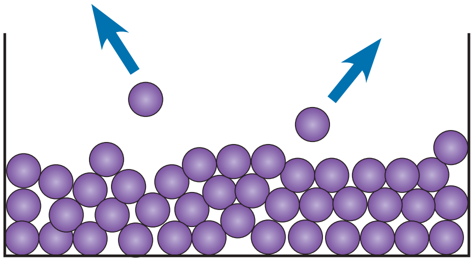
When a liquid becomes a gas, the particles move faster and spread out. The attractive forces between the particles become very weak.

A substance in the liquid state becomes a gas by **evaporation** or by **boiling**.

Clothes dry when water evaporates from them.

Evaporation

Evaporation happens when particles leave the surface of a liquid. The particles spread out to form a gas. Evaporation can happen at any temperature.

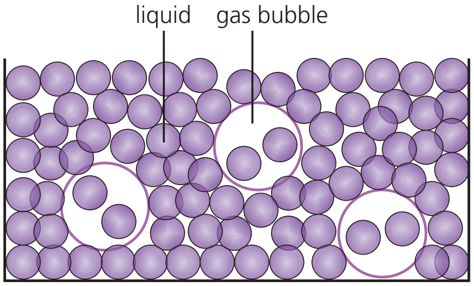


During evaporation, particles leave the liquid surface. *Not to scale.*

Water is constantly evaporating from lakes and the sea.

Boiling

Boiling occurs throughout the whole of a liquid. When you heat a beaker of liquid water, bubbles of water in the gas state form throughout the liquid. The bubbles rise to the surface and escape. The water is boiling. Boiling can only happen when a liquid is hot enough.



When a liquid is boiling, bubbles of gas form throughout. *Not to scale.*

Boiling point

Different substances boil at different temperatures. The temperature at which a substance boils is its **boiling point**. Every substance has its own boiling point.

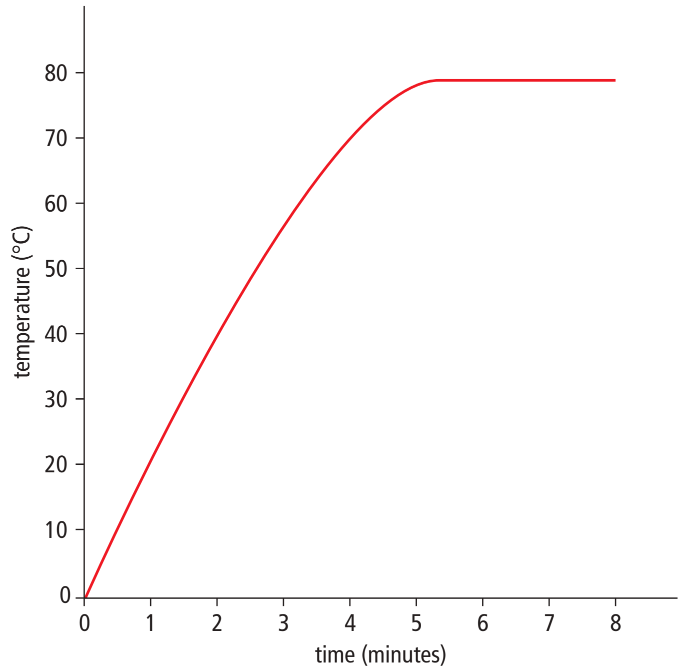
Substance	Boiling point (°C)
nitrogen	–196
ethanol	78
water	100
mercury	357
copper	2595
diamond	5100

Nitrogen has the lowest boiling point of the substances in the table. Diamond and copper have very high boiling points.

Measuring boiling point

Mbizi has a colourless liquid. He knows that the liquid is either ethanol or water, but does not know which. To find out, Mbizi uses an electric heater to heat the liquid. Ethanol is very flammable and so Mbizi is very careful; he wears safety goggles and a lab coat. He measures its temperature every minute. He plots the data on a graph.

The graph shows that the temperature of the liquid increased for the first five minutes. Then the temperature stayed at 78 °C for three minutes while the liquid boiled. The boiling point of the liquid is 78 °C. Data from the table show that the liquid is ethanol.



The graph shows how the temperature of the liquid changed.

Gas to liquid

When a substance changes state from gas to liquid, the particles move more slowly. They get closer until they touch each other. The forces of attraction between the particles are much stronger in the liquid.

A gas becomes a liquid by **condensation**. A substance in the gas state condenses when it is cooled to its boiling point or below.

Q

1. Name the change of state when a substance in the gas state becomes a liquid.
2. Describe how the movement of the particles change when a substance boils.
3. Use data from the table at the top of the page to name one substance which is in the gas state at 20 °C.
4. Suggest how a scientist could measure the boiling point of a piece of metal.

!

- A liquid evaporates or boils to form a gas.
- A gas condenses to form a liquid.
- Every substance has its own boiling point.

Enquiry

1.3 Questions, evidence, and explanations

Objective

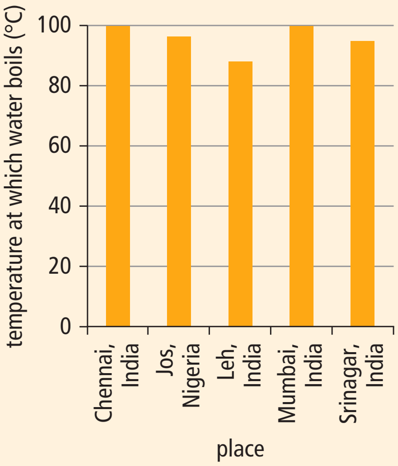
- Understand why questions, evidence, and explanations are important in science

A boiling question

Rabia is a school student. She lives in Mumbai, a city by the sea. She visits Leh, high in the mountains. She discovers that water boils at different temperatures in the two places. Rabia wonders why. She decides to find out scientifically.

Many scientific investigations start with **questions**. Rabia's question is:

Why does water boil at different temperatures in different places?



Collecting evidence

Rabia collects **evidence** to help answer her question. She uses a thermometer to measure the boiling point of water in Mumbai. She asks her relatives to measure the temperature at which water boils in other places. She plots their results on a bar chart.

Rabia thinks about her evidence. So far, she realises, she hasn't answered her question. All she knows is that water boils at 100 °C in Mumbai and Chennai, but at different temperatures in the other places.

An idea, and more evidence

Rabia looks at her evidence again. She notices that the temperature at which water boils in cities by the sea (Chennai and Mumbai) is higher than the boiling temperatures recorded in the mountain towns of Srinagar, Leh, and Jos. Rabia has an idea – maybe the boiling point of water depends on altitude (height above sea level) of the place at which it is measured.

Rabia decides to test her idea. She collects evidence from the Internet. She writes the evidence in a table.

Place	Altitude (metres above sea level)	Temperature at which water boils (°C)
Chennai, India	0	100
Jos, Nigeria	1200	96
Leh, India	3524	88
Mumbai, India	0	100
Srinagar, India	1585	95
Summit of Mount Everest, Nepal	8550	69
Summit of Puncak Jaya, Indonesia	4884	83

A scientific explanation

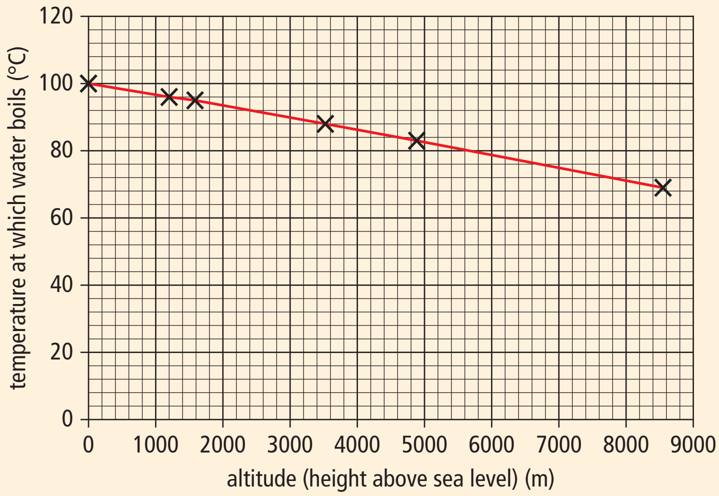
Rabia uses the evidence in the table to draw a line graph. This will make it easier to spot patterns.

Rabia describes the pattern shown by the graph:

The boiling point of water depends on the altitude.

The higher the altitude, the lower the boiling point.

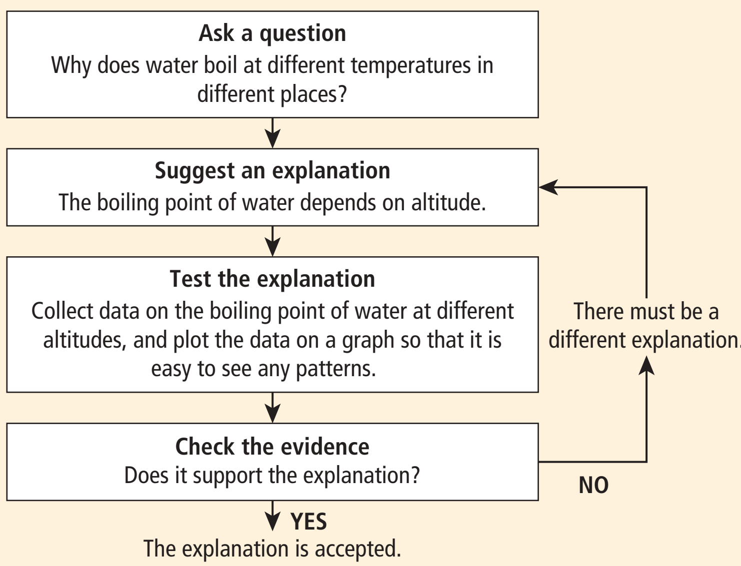
Rabia has used evidence, and her ideas, to develop a scientific **explanation**. Scientific explanations must be supported by evidence.



More questions

Rabia's explanation leads her to think of new questions. She wonders *why* altitude affects the temperature at which water boils, and if the boiling points of liquids other than water also depend on altitude.

If Rabia wants to answer her questions, she will need to collect extra evidence – and think creatively about this evidence – before she can develop scientific explanations.



➡ Rabia found out why the boiling point of water was different in different places by asking a question and testing an explanation.

Q

1 Suggest how Rabia could investigate scientifically whether the boiling points of liquids other than water depend on altitude, and draw a flow chart to summarise how she could develop her explanation.

2 Rabia's teacher says that the higher the altitude, the smaller the number of particles in a given volume of air. Suggest how this new piece of evidence might help Rabia to develop an explanation about *why* altitude affects boiling point.

!

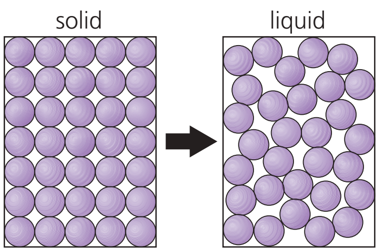
To develop explanations, scientists:

- ask questions
- suggest ideas
- collect and consider evidence.

1.4 Melting, freezing, and subliming

Objectives

- Name and explain changes of state involving solids
- Describe how melting points help identify substances



When a substance melts, the movement and arrangement of its particles change.

Solid to liquid

The change of state from solid to liquid is called **melting**. When a solid melts, its particles move out of their regular pattern. The particles start to move around, in and out of each other. This means that the particle arrangement changes all the time.

The particles touch each other when a substance is in both its solid and liquid states.

Melting point

Different substances melt at different temperatures. The temperature at which a substance melts is its **melting point**. Every substance has its own melting point.

Substance	Melting point (°C)
nitrogen	–210
mercury	–39
water	0
gold	1063
copper	1083

Gallium melts on your hand. Its melting point is 30 °C.

Gold melts at a very high temperature.

Using melting points

Scientists use melting point to help identify substances. Sarah has a white solid. She heats the solid until it melts. Its melting point is 561 °C. She uses a data book to find that one substance with this melting point is calcium nitrate. Sarah concludes that her white solid might be calcium nitrate. She decides to do further tests to make sure.

Melting temperatures also tell you about the purity of a substance. If a substance has a sharp melting point, it is not mixed with anything else – it is a **pure substance**. If a substance melts over a range of temperatures, it is a mixture of substances.

This apparatus measures melting point accurately.

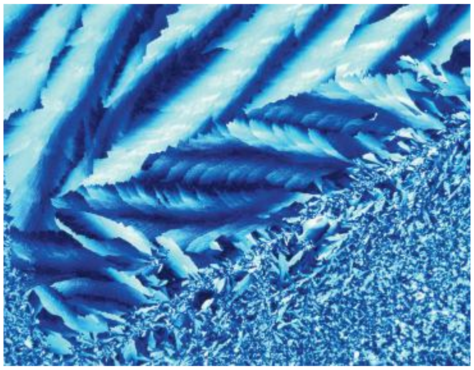
Liquid to solid

The change of state from liquid to solid is called **freezing**. Freezing is the opposite of melting. When a liquid freezes, its particles stop moving around from place to place. They arrange themselves in a regular pattern, and vibrate on the spot.

The temperature at which a substance freezes is its **freezing point**. Every substance has its own freezing point. The freezing point of a pure substance is the same as its melting point. For example:

- Freezing point of water = 0 °C
- Melting point of water = 0 °C

Butter and ghee are mixtures of substances, so they melt over a range of temperatures. They do not have sharp melting points.



This photograph shows ice crystals forming from liquid water. The photograph was taken in polarised light.

Sublimation

Most solids melt to form liquids when you heat them. But some solids do not change state to become liquids. Instead, they become gases. The process is called **sublimation**. A solid **sublimes** when it changes directly into a gas, without first becoming a liquid.

Solid carbon dioxide – also called dry ice – sublimes to make carbon dioxide gas. It is used in stage shows, such as rock concerts.

Solid grey iodine sublimes on heating to make a purple gas. When it cools, it forms solid iodine again.

Q

1 Name the change of state when a substance in the solid state becomes a liquid.

2 Describe how the movement and arrangement of particles change when a substance freezes.

3 Jati has a sample of a solid. Suggest how he could find out whether the solid is a pure substance or a mixture of substances.

!

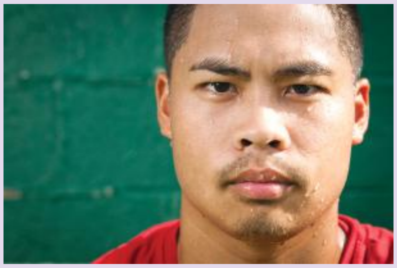
- A solid melts to become a liquid.
- A liquid freezes to become a solid.
- Some solids sublime to form gases.
- Every substance has its own melting / freezing point.

Extension 1.5

Energy and changes of state

Objective

- Use ideas about energy to explain changes of state



Water particles in sweat take heat energy from your skin. They use this energy to evaporate. This is why sweating cools you down.

Liquid nitrogen takes in energy from the surroundings. The temperature increases to its boiling point. Bubbles form throughout the liquid nitrogen. It boils and changes to the gas state.

Melting copper.

Forces between particles

When a substance is in its solid or liquid state, strong forces hold the particles together. The forces between particles are much weaker when a substance is in its gas state.

Energy for boiling and evaporation

In a liquid, the particles touch each other. Strong forces of attraction between the particles stop them escaping from the liquid.

Particles in liquids move around. Some particles move faster than others. The faster moving particles have more energy.

Evaporation happens when some faster-moving particles have enough energy to overcome the forces that hold the particles together. These particles escape from the surface of the liquid.

Boiling happens when, overall, the particles in a liquid move quickly enough to overcome the forces holding them together. A liquid needs energy from heating to make its particles move quickly enough. This is why a substance can only boil when it is at its boiling point.

Explaining boiling points

The boiling point of a substance depends on the strength of the forces between the particles in the liquid state. The stronger the forces, the more energy is needed to separate the particles, and the higher the boiling point.

Explaining melting

When a substance is in its solid state, strong forces hold the particles in a pattern. Energy is needed to overcome these forces to make the solid melt.

Your hand can supply enough energy to melt a small piece of gallium metal or an ice cube. Much more energy is needed to melt a small piece of copper.

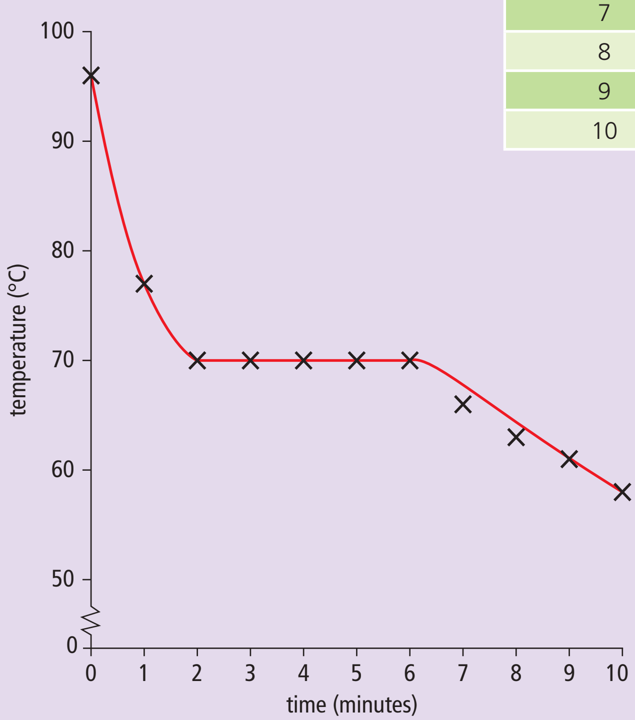
The melting point of a substance depends on the strength of the forces that hold the particles in a pattern. The stronger these forces, the more energy is needed to make the solid melt, and the higher the melting point.

Explaining freezing

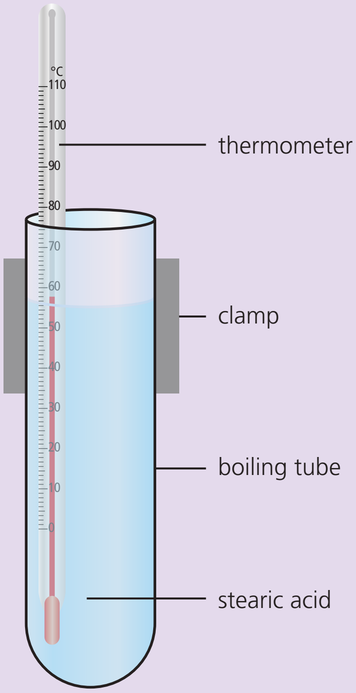
Obi investigates how stearic acid cools. He pours hot liquid stearic acid into a test tube and lets it cool. He records the temperature every minute. His results are in the table.

Obi plots his data on a graph, and draws a smooth curve.

Time (min)	Temperature (°C)
0	96
1	77
2	70
3	70
4	70
5	70
6	70
7	66
8	63
9	61
10	58



The graph shows that stearic acid freezes at 70 °C. At this temperature, the particles transfer energy to the surroundings. They stop moving around from place to place, and arrange themselves in a pattern.



Apparatus to investigate cooling.

The liquid water in food freezes in a freezer. The water does not freeze instantly. It takes time for energy to leave the water, and for the water particles to arrange themselves in a pattern.

Q

1. Describe how the strength of the forces between particles change when a liquid becomes a gas.
2. Describe and explain what happens to the particles when a liquid evaporates.
3. The boiling point of copper is 2595 °C. The boiling point of gold is 2970 °C. Predict which substance has stronger forces between the particles in the liquid state. Explain your answer.

!

- Boiling and melting need energy.
- Energy leaves a substance when it freezes.

1.6 Using particle theory to explain dissolving

Objectives

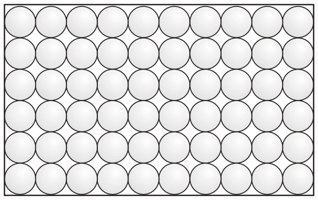
- Use particle theory to explain dissolving
- Understand what a secondary source is
- Practise making conclusions from data

Making a solution

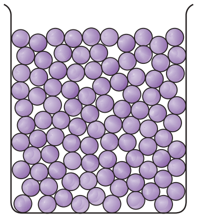
Kasarna makes coffee. She pours hot water over coffee powder, then she adds sugar and stirs. The sugar and coffee powder **dissolve**. Kasarna has made a **solution**. Water is the **solvent**. Sugar and the substances from the coffee powder are **solutes**.

Using particles to explain dissolving

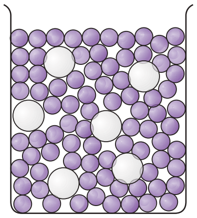
When a substance dissolves, it mixes with the solvent. The particles of both substances are randomly arranged in the container. The diagrams below show what happens.



Particles in solid sugar (not to scale).



Particles in liquid water (not to scale).



Particles in sugar solution (not to scale).

What happens to the solute particles?

Amun adds sugar to a cup of tea. The sugar seems to disappear. Amun wants to check that the sugar is still there, so he does an experiment. The experiment involves:

1. Finding the mass of a glass of water.
2. Weighing out 10 g of sugar.
3. Adding the sugar to the water, with stirring.
4. Finding the mass of the solution.

The mass of the solution is the same as the masses of the water and sugar added together. The sugar particles have not disappeared!

How much solute can dissolve in a solvent?

Sunanda likes sweet tea. One day, for an experiment, she puts 60 spoons of sugar in a glass of tea and stirs the mixture. Some sugar stays in the bottom. It doesn't dissolve. Sunanda has made a **saturated solution**.

There is a limit to the mass of a substance that dissolves in 100 g of water. This is the **solubility** of the substance. Every substance has a different solubility. The greater the mass of a substance that will dissolve in water, the more **soluble** the substance.

Collecting information from secondary sources

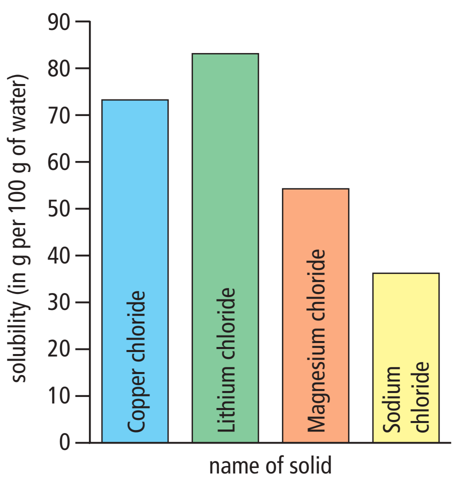
Sunanda wants to compare the solubility of different substances. She cannot do an experiment to measure solubilities, since she does not have a balance to measure mass.

Sunanda collects data from a chemistry data book. The book is a **secondary source**. Secondary sources provide evidence that you have not collected by doing an investigation yourself. They include books, scientific journals, and the Internet. If another student gives you evidence from his investigation, the student is a secondary source.

You can trust some secondary sources more than others. **Scientific journals** are collections of papers written by scientists, which describe their work. Other scientists check the papers carefully. This means that evidence from scientific journals is usually trustworthy. You can also trust evidence in data books and text books. However the quality of evidence from the Internet varies.

Making conclusions from data

Sunanda uses her data to draw a bar chart. The bar chart shows the masses of different substances that dissolve in 100 g of water.



Practise making conclusions from bar charts by answering question 4.

Q

1. Define these words: dissolve, solution, solvent, solute, solubility.
2. Describe how to do an experiment to show that when you dissolve salt in water the salt is still there.
3. Suggest how to do an experiment to find the solubility of salt.
4. Use the bar chart above to identify:
   - **a** The most soluble substance shown on the bar chart.
   - **b** The least soluble substance shown on the bar chart.
   - **c** The solubility of copper chloride.

!

- A solution is a mixture of solute and solvent particles.
- Solubility is the mass of a solid that dissolves in 100 g of water.
- Secondary sources give evidence collected by others.

Enquiry

1.7

Planning an investigation

Objective

- Understand the processes involved in planning an investigation

Suggesting ideas to test

Zahra notices that she can dissolve more sugar in hot tea than in cold tea. She wonders if this is true for other solids, such as sodium carbonate.

She decides to investigate the question:

How does water temperature affect the mass of sodium carbonate that dissolves?

Making a prediction

Zahra knows that more sugar dissolves in hot tea than in cold tea. She does a quick experiment with sugar and water, instead of tea. She finds that more sugar dissolves in hot water than in cold water.

Zahra uses her scientific knowledge to make a **prediction**. She thinks that sodium carbonate might behave in the same way as sugar.

She predicts that:

As the temperature of water increases, the mass of sodium carbonate that dissolves will increase.

Considering variables

Zahra lists all the possible **variables** in her investigation. A variable is a quantity or characteristic that can change. Here is her list:

- *water temperature*
- *water volume*
- *mass of sodium carbonate that dissolves*
- *size of pieces of sodium carbonate*
- *speed of stirring*

Zahra makes decisions about the variables:

Variable to change – water temperature

Variable to observe – mass of sodium carbonate that dissolves

Zahra wants her investigation to be a **fair test**, so she must control the other variables. She will use the same volume of water for each test, and pieces of sodium carbonate of the same size. She will stir at the same speed.

Identifying evidence to collect

Zahra thinks about the evidence she will need to help her answer her question:

How does water temperature affect the mass of sodium carbonate that dissolves?

She decides to measure out 100 cm^3 of water and cool it to 0 °C. She will add sodium carbonate, 1 g at a time, and stir the mixture until no more dissolves. She will repeat this procedure at different temperatures.

Choosing and using apparatus

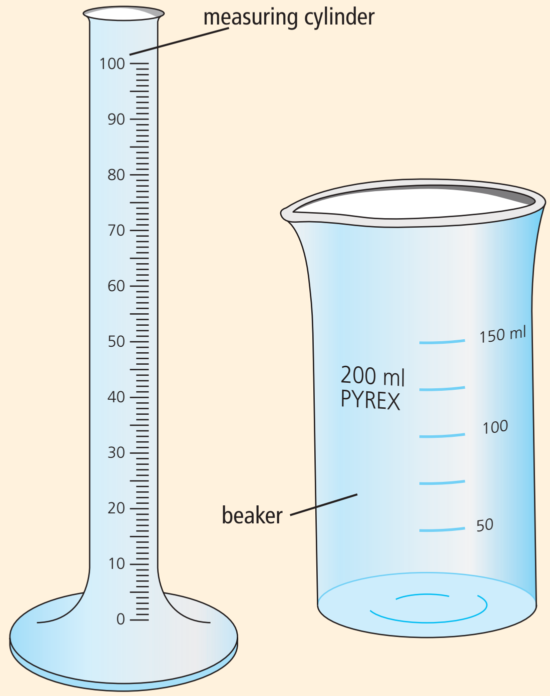
Zahra needs to choose suitable apparatus for her investigation.

Zahra could use a **measuring cylinder** or a **beaker** to measure the volume of water. She chooses a measuring cylinder because it measures smaller differences in volume.

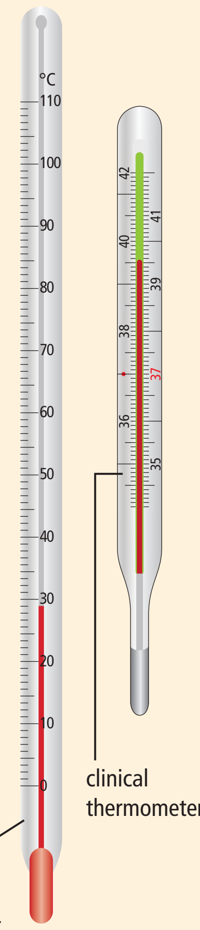
Zahra has a choice of two **thermometers**. The clinical thermometer measures temperatures between 35 °C and 42 °C. Zahra wants to measure over a wider range of temperatures, so she chooses a thermometer with a measurement range of 0 °C to 110 °C.

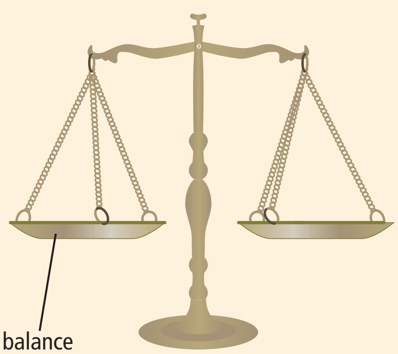
Zahra's school has two instruments to measure mass. She can use the **balance** with balance weights, to measure mass changes as small as 1 g. The balance works without electricity. The **electric balance** measures smaller differences in mass. Zahra decides to use the balance with balance weights since her electricity supply is unreliable.

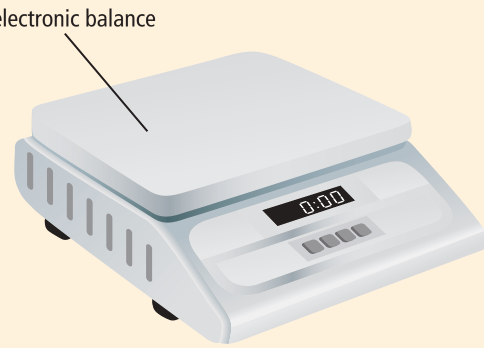
Zahra uses a **Bunsen burner** to heat the water, and a **stirring rod** to stir the mixtures.

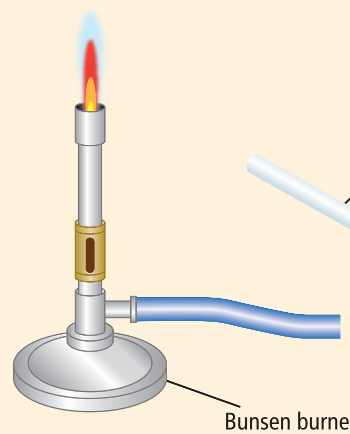


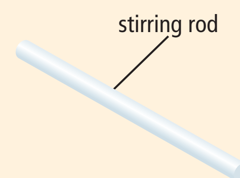
The measuring cylinder measures a difference in volume of 1 cm^3. The beaker measures a difference of 25 cm^3.











Making observations

Zahra uses her apparatus to find the mass of sodium carbonate that dissolves in water at five different temperatures. She makes measurements and observations. Her results are on the next page.

Q

1. What is a variable?
2. Explain why Zahra kept some variables constant in her investigation.
3. Suggest how Zahra could investigate the question: how does the speed of stirring affect the time for salt to dissolve in water? Include a list of variables and apparatus choices in your answer.

!

Planning an investigation involves:

- asking questions
- making predictions
- considering variables
- identifying evidence to collect
- choosing apparatus.

Enquiry

1.8 Presenting evidence

Objective

- Present evidence in tables and line graphs

Presenting evidence in a table

Zahra is investigating the question:

How does water temperature affect the mass of sodium carbonate that dissolves?

She begins to collect evidence, and notes her observations and measurements on a scrap of paper.

At 0 °C 7 g of solid dissolved when I stirred it, and at 10 °C about 12 g dissolved.

Zahra knows she will need to look for patterns in her evidence. She decides to organise the data in a table. If the data are organised, it will be easier to spot patterns.

Water temperature (°C)	Mass of sodium carbonate that dissolves (g)
0	7
10	12
20	22
30	39
40	49

When you draw tables:

- write the variable you change in the left column
- write the variable you observe or measure in the right column
- include units in the column headings.

Bar chart or line graph?

Zahra looks carefully at the data in the table. She notices that, as the water temperature increases, so does the mass of sodium carbonate that dissolves. Her prediction is correct.

Zahra decides to examine the pattern more closely. She wants to draw a bar chart or line graph. But which is more suitable?

- Draw a bar chart when the variable you change is **discrete**. A discrete variable is a variable whose values are words, or whose values can have only certain numerical values.
- Draw a line graph when the variable you change is **continuous**. A continuous variable can have any value.

The variable Zahra changes – temperature – is continuous. It can have any value. A line graph will show changes in the mass that dissolves as temperature increases.

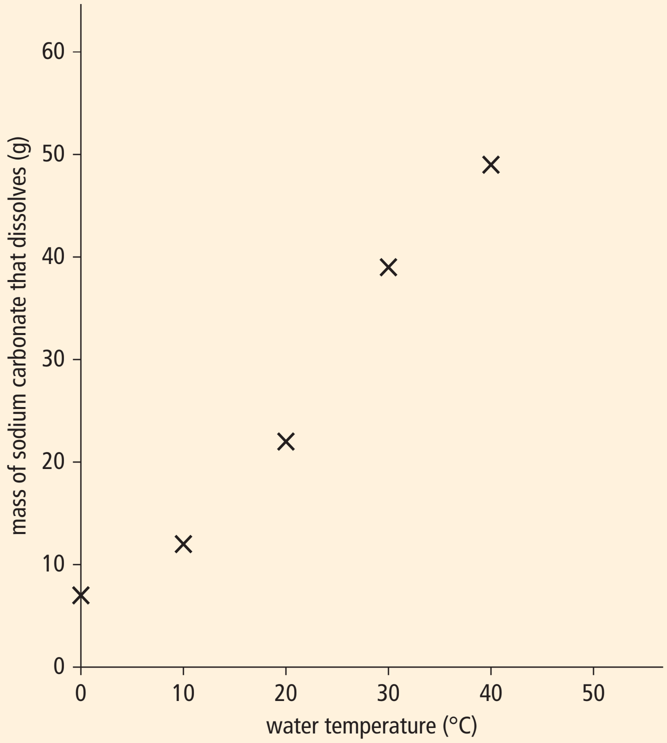
Drawing a line graph

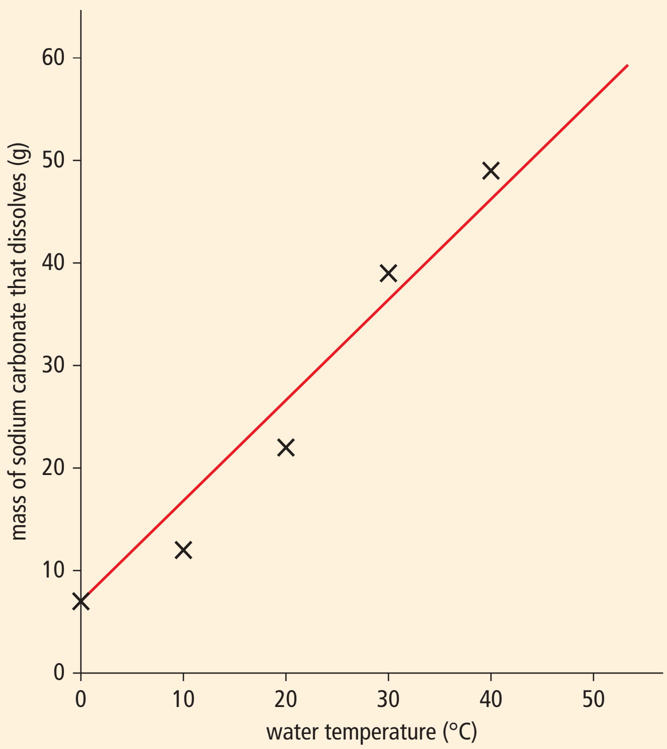
Zahra plots her data on a graph.

When you draw a line graph:

- label the *x*-axis with the name and units of the variable you change
- label the *y*-axis with the name and units of the variable you observe
- choose a scale for each axis
- write values on the lines on the *x*-axis – use evenly spaced numbers
- write values on the lines on the *y*-axis – use evenly spaced numbers.

Then draw a line of best fit to show the pattern. The line of best fit can be a curve or a straight line. Zahra decides to draw a straight line on her graph.





Choosing scales

To choose scales for the axes on a line graph:

1. Find the difference between the biggest *y*-value and the smallest *y*-value. This is the **range**.
2. Divide the range by the number of squares on the *y*-axis.
3. Round up your answer to choose the interval that each square represents.
4. Repeat steps 1–3 for the *x*-axis.

Q

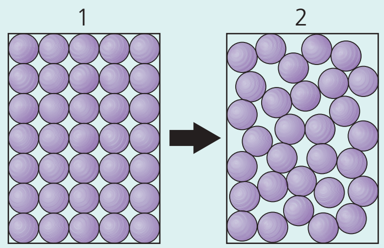
1. What is a discrete variable?
2. Explain why Zahra recorded her results in a table.
3. Explain why Zahra decided to present her results in a line graph, not a bar chart.
4. Another student collected boiling point data for 10 different substances. Should he display his results in a line graph or a bar chart? Explain your answer.

!

- Use tables to organise data as you collect it.
- Draw a bar chart if the variable you change is discrete.
- Draw a line graph if the variable you change is continuous.

Review 1.9

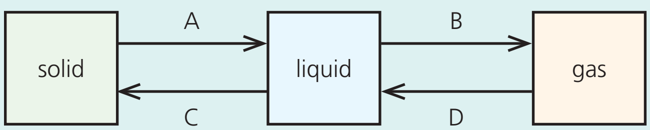
1 The diagram shows the particles in solid water (ice) and in liquid water.



a Describe how the particles move in the solid. [1]

b Describe one difference in the arrangement of the particles in ice and in liquid water. [1]

2 In the diagram below, each arrow represents a change of state.



a Which arrow represents freezing? [1]

b Which arrow represents condensing? [1]

c Give the name of the change of state represented by arrow A. [1]

3 Oxygen is a gas at 20 °C.

a Describe the arrangement and behaviour of the particles in the gas. [3]

b Use ideas about particles to explain why oxygen gas can be compressed. [1]

4 A student heats a piece of solid metal. The metal remains solid. Why does it get bigger? Choose the correct answer from the list below.

The particles get bigger.

The particles get further apart.

The particles move around from place to place. [1]

5 Complete the sentences using words from the list. You may use them once, more than once, or not at all.

increases **decreases** **stays the same**

a When liquid water boils, the distance between the particles ___________. [1]

b When liquid water boils, the strength of the attractive forces between the particles ______. [1]

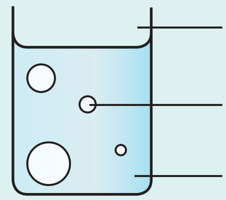
c When steam condenses, the speed of movement of the particles ___________. [1]

6 Write the letter of each label next to the correct line on the diagram.

A Water in the liquid state.

B Water in the gas state (steam).

C Mixture of air and steam.



[3]

7 The table gives the melting points and boiling points for five substances.

Substance	Melting point (°C)	Boiling point (°C)
bromine	–7.2	59
chlorine	–101.5	–35
iodine	113.6	184.4
krypton	–157.2	–152.3
osmium	3000	5000

a Name the substance in the table with the lowest melting point. [1]

b Name the substance in the table with the lowest boiling point. [1]

c Name two substances in the table that are gases at 20 °C. [1]

d Name two substances in the table that are solids at 20 °C. [1]

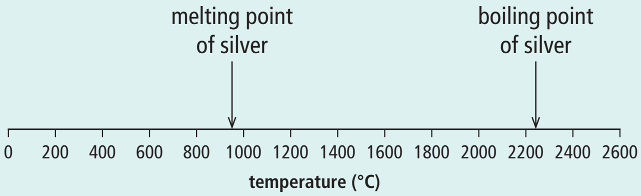
e Complete the sentence using words from the list. You may use them once, more than once, or not at all.

solid **liquid** **gas**

When bromine is heated from 20 °C to 100 °C it changes from a _______ to a _______. [1]

f Name the change of state that occurs when osmium is heated from 4000 °C to 6000 °C. [1]

8 The diagram shows the melting point and the boiling point of silver.



a What is the state of silver at 2000 °C? [1]

b Name the change of state that occurs when silver is heated from 0 °C to 1000 °C. [1]

9 Read the statements below about the particles in liquid water. All the statements are true.

A The particles touch their neighbours.

B The particles are not arranged in a regular pattern.

C The particles move around, in and out of each other.

a Write the letter of the one statement above which best explains why you can pour liquid water. [1]

b Write the letter of the one statement above which best helps to explain why the volume of 1 g liquid water is similar to the volume of 1 g of solid water (ice). [1]

10 A student had some liquid salol. She allowed it to cool. Every minute, she measured the temperature of the salol. Her results are in the table below.

Time (min)	Temperature (°C)
0	70
1	56
2	42
3	42
4	42
5	30
6	20

a Name the variable that the student changed. [1]

b Name the variable that the student observed. [1]

c Plot the points in the table on a graph, and draw a line of best fit. [3]

d Use the graph to work out the freezing point of salol. [1]

e Describe what happens to the movement and arrangement of the particles when liquid salol freezes. [1]

11 A student wrote down a question to investigate: *How does the temperature of water affect the mass of potassium chloride that will dissolve in it?*

a The student listed some variables in the investigation:

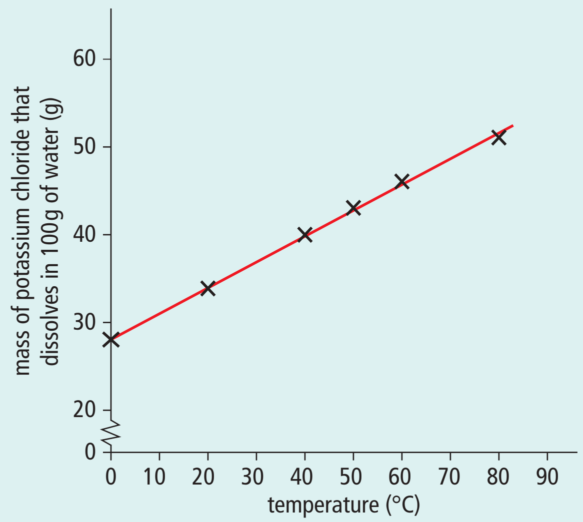
temperature of water
volume of water
mass of potassium chloride that dissolves
amount of stirring

i From the list above, identify the variable the student will change. [1]

ii From the list above, identify the variable the student will observe. [1]

iii From the list above, identify two variables the student will control. [1]

b The student made a prediction:
The hotter the water, the greater the mass of potassium chloride that will dissolve.
He collected results and plotted a graph.



Do the results on the graph agree with the prediction? Explain your answer. [1]

12 A student does an investigation to find the solubility of different substances in water. She writes down her results.

> At 20 °C 36 g of sodium chloride dissolved in 100 g of water. For potassium chloride it was 34 g. Then I tested potassium nitrate, and 47 g dissolved in 100 g of water.

a Write the missing column heading, and the results, in the table below. [2]

	mass of substance that dissolved in 100 g of water (g)

b Draw a bar chart to show the results in the table. [3]

c Explain why the results should be shown on a bar chart, and not on a line graph. [2]

d Give the names of three pieces of apparatus the student might use to do the investigation. [2]

2.1 Introducing elements

Objectives

- Understand what materials are
- Explain what an element is
- Find metals and non-metals on the periodic table
- Give examples of elements

What are things made of?

Look around you. Can you see anything made of wood, plastic, or cotton? Wood, plastic, and cotton are example of **materials**. Materials are the different types of matter that things are made of. There are millions of different materials. They do an amazing variety of things.

How we use a material depends on its **properties** – what the material is like, and how it behaves. For example, wood is stiff and strong, and it looks attractive. These properties mean that wood is a good material for making tables.

Elements

Every material – and everything in the Universe – is made from one or more **elements**. An element is a substance that cannot be split into anything simpler.

There are 92 different types of element found naturally on Earth. Scientists have made at least another 25 elements. Each element is made of its own type of particle, which is unique to that element. And every element has its own properties.

The periodic table

The **periodic table** lists all the elements, and groups together elements with similar properties.

The periodic table opposite shows a stepped line. The elements on the left of the line are **metals**. The elements on the right of the line are **non-metals**.

Q

1. What is an element?
2. Identify two types of element that are shown on the periodic table.
3. Use the periodic table to list six metal elements and six non-metal elements.
4. Suggest two properties of a typical metal.

!

- Materials are the different types of matter things are made of.
- Everything is made up of one or more elements.
- The elements are listed on the periodic table, with metals on the left of the stepped line and non-metals on the right.

Potassium is vital to life – it keeps your heart, kidneys, and nerves working. You cannot eat pure potassium, but foods like peanuts and bananas contain potassium joined to other elements.

Hydrogen is a colourless gas at 20 °C. It is the most common element in the Universe.

All living things contain carbon – including you!

Nitrogen is a non-metal. It is the most common element in the Earth's atmosphere.

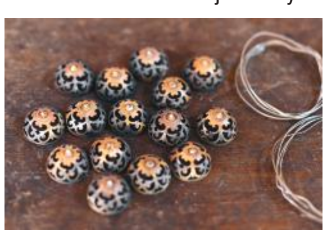
Helium is the second most common element in the Universe.

			Hydrogen														Helium
Lithium	Beryllium											Boron	Carbon	Nitrogen	Oxygen	Fluorine	Neon
Sodium	Magnesium											Aluminium	Silicon	Phosphorus	Sulfur	Chlorine	Argon
Potassium	Calcium	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Gallium	Germanium	Arsenic	Selenium	Bromine	Krypton
Rubidium	Strontium	Yttrium	Zirconium	Niobium	Molybdenum	Technetium	Ruthenium	Rhodium	Palladium	Silver	Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	Xenon
Caesium	Barium	Lanthanum	Hafnium	Tantalum	Tungsten	Rhenium	Osmium	Iridium	Platinum	Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon
Francium	Radium	Actinium	Rutherfordium	Dubnium	Seaborgium	Bohrium	Hassium	Meitnerium	Darmstadtium								

The periodic table of the elements. Some elements have been omitted.

Most of the metal objects that we use contain the element iron. Worldwide, more iron is produced than any other element.

Silver makes attractive jewellery.



Copper is a metal. It is an excellent conductor of electricity.

Mercury is a metal. It is the only metal that is liquid at room temperature (20 °C).

Oxygen and silicon are the two most common elements in the Earth's crust (the outer layer of the Earth). These elements are often found joined to each other or other elements.

2.2 Metal elements

Metal elements

Objectives

- Identify typical metal properties
- Link the properties of two metals to their uses

Metal elements

Do you use a phone? Travel by bus or bicycle? Wear jewellery? All of these contain metals. About three-quarters of the 92 elements that are found naturally on Earth are metals.

Metals have similar physical properties to each other. Their properties make them useful.

Physical properties of metals

State and appearance

Most metals have high melting and boiling points. All metals, except mercury, are in the solid state at 20 °C.

All metals are shiny when you first cut them, or if you rub them with sandpaper. After a while most metals go dull on the outside, but gold and platinum are always shiny – that's why they make such good jewellery.

Sonority

When you hit a metal it makes a ringing sound. Scientists say that metals are **sonorous**.

Metals are sonorous, so they are used to make bells.

Conduction of heat and electricity

Metals are good conductors of heat and electricity. This means that heat and electricity travel through metals easily.

Some metals conduct electricity better than others – the best are copper and silver. The best conductors of heat are copper and gold.

Other properties

Most metals are **strong**. Big forces are needed to break or squash them.

Many metals are **hard**. It is not easy to scratch them.

Most metals have a high **density**. They feel heavy for their size.

Thin metal sheets are bendy. So when a car crashes its metal body doesn't break into lots of little pieces – it just bends.

The metal in this car bent when it crashed.

Metals are also:

- **malleable** – they can be hammered into shape without cracking.
- **ductile** – they can be pulled out to make wires.

Using metals

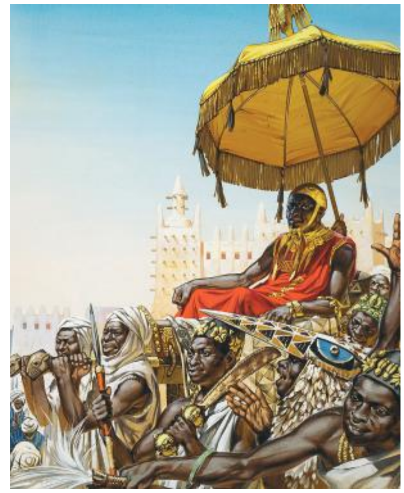
Metal elements do not have exactly the same properties as each other. The properties of a particular metal explain how we use it. Read on to learn about the properties and uses of two important metals.

Gold

Gold is a shiny, yellow metal. It is malleable and ductile, and stays shiny in air and water. These properties mean that gold makes excellent jewellery and coins.

Today, gold is also used to make electrical connectors in audio equipment such as speakers. It is also used in printed circuit boards. Gold is perfect for this job because it conducts electricity well and it is not damaged by air.

Skilled craftspeople made this jewellery in Egypt 3500 years ago.



Mansa Musa, a king in Mali, traded gold in the 1300s.

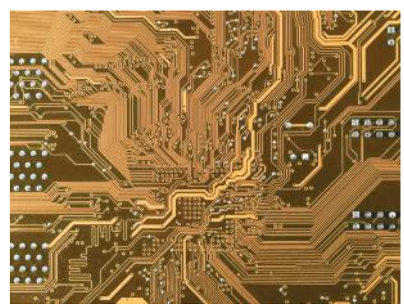
Iron

Iron is a shiny, grey metal. Worldwide, we use more iron than any other metal. Iron is the main metal in ships, cars, and tools. Iron is used because, when mixed with small amounts of other elements, it is strong and malleable. It is also cheap compared to other metals.

Gold jewellery is still valued.

Shipping containers are mainly iron.

Iron usually goes rusty, but this iron pillar has stood in Delhi, India, for 1500 years. The climate prevents rust forming.



A gold-plated printed circuit board.

Q

1. List six physical properties of a typical metal.
2. Platinum is a typical metal. Identify two properties of platinum which mean it makes good jewellery.
3. Suggest two metal properties that explain why they are used for making buses.

!

- Most metals are shiny and sonorous.
- Metals are good conductors of heat and electricity.
- A typical metal is strong, hard, malleable, ductile, and has a high density.

2.3 Non-metal elements

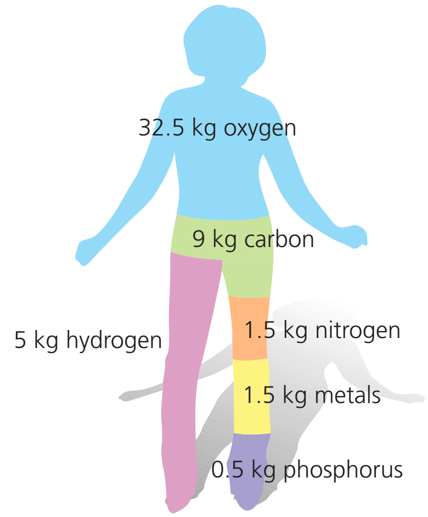
Objectives

- Identify typical non-metal physical properties
- Link the physical properties of non-metals to their uses

The elements of life

Only about twenty elements are not metals, but they are very important.

Every living thing is made mostly from non-metal elements, joined together to make substances with particular physical properties. Your muscles are mainly made of carbon, hydrogen, oxygen, nitrogen, and sulfur. The picture shows the elements that make up the body of a 50 kg person.



The non-metal elements are shown on the right of the stepped line on the periodic table (see p. 27).

Physical properties of non-metals

The properties of a typical non-metal are different from the properties of a typical metal.

Boiling and melting points

Compared to metals, most non-metals have low melting and boiling points. This means that some non-metal elements exist as gases at 20 °C.

This balloon is filled with helium gas.

Neon gas makes these signs glow brightly.

Hospitals use oxygen gas to help treat patients.

Solid non-metal elements

A few non-metals – like sulfur, carbon, and phosphorus – exist as solids at 20 °C. Most are not shiny. They are usually **brittle,** which means that they break easily if you hit them with a hammer. You cannot bend solid non-metals. Most non-metals do not conduct electricity.

Sulfur is a typical non-metal. As a solid, it is dull, brittle, and does not conduct electricity.

There are three types of phosphorus. White phosphorus quickly catches fire in air, and is a deadly poison. Phosphorus fire bombs were used in World War II.

Carbon

Carbon is a very special non-metal. There are several types of solid carbon. In each type of carbon the particles have a different arrangement. This means that each type of carbon has its own physical properties.

This drill has a hard diamond tip.

The softness of graphite makes it useful for pencils.

Diamond

The pattern of particles in one form of carbon, diamond, forms beautiful crystals. The crystals are incredibly hard – diamond drills and cutting tools cut through almost anything. Like most non-metals, diamond does not conduct electricity.

Graphite

In another form of carbon, graphite, the particles are arranged in layers. This makes graphite soft, like most other non-metals. But graphite is unlike other non-metals in one way – it is a good conductor of electricity.

Metalloids

Computers and cell phones rely on microchips. These are electronic circuits made with tiny pieces of the element silicon. Silicon is a **semiconductor**. It conducts electricity less well than metals, but better than non-metals.

Silicon exists as a shiny, grey solid at 20 °C. It is not bendy, but brittle – it smashes easily if you hit it with a hammer. Its brittleness makes it more like a non-metal than a metal. But silicon conducts electricity, which is what metals do. Scientists classify silicon as a **metalloid** or **semi-metal**.

There are other elements with properties similar to silicon, including germanium, boron, arsenic, and antimony. They are all metalloids, and are close to the stepped line on the periodic table.

Q

1. List three physical properties of a typical non-metal element.
2. Explain what makes sulfur a typical non-metal.
3. **Extension:** Draw a table to compare the physical properties of two forms of carbon: diamond and graphite.

!

- Most non-metals have low boiling and melting points.
- Some non-metals exist as gases at 20 °C.
- Most non-metals are brittle and dull when in the solid state.

Enquiry
2.4

Making conclusions from data

Objective

- Practise drawing conclusions from data in tables and graphs

Making conclusions from data in tables

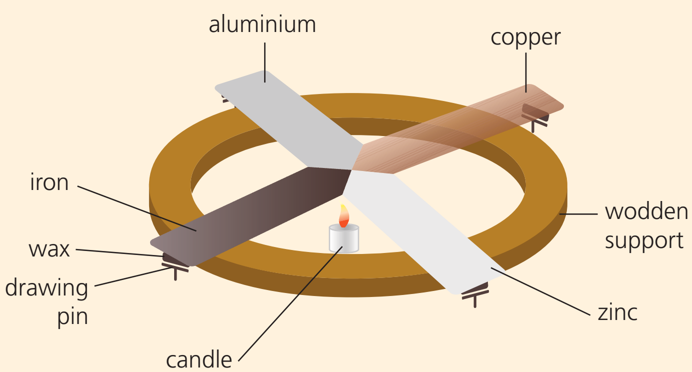
Comparing how well metals conduct heat

Catherine is investigating the question:

Which of the metals aluminium, copper, iron, and zinc is the best conductor of heat?

She sets up the apparatus below. The size of each rod is the same. She measures the time for the pin to fall off each metal rod.

Catherine collects the data in Table A below.



Metal	Time from start of heating until pin drops off (s)
aluminium	18
copper	10
iron	39
zinc	35

Table A. Catherine's results.

She examines the data in the table. She notices that the pin on the copper rod dropped off most quickly. Heat must have travelled along the copper rod more quickly than along the other rods.

Catherine makes a conclusion:

Of the four metals tested, copper was the best conductor of heat.

Metal or non-metal?

Ketan collects data from a text book to test his friend Darshan on the differences between metal and non-metal elements. The data is in Table B below.

Element	Appearance	Does the element conduct electricity?	Melting point (°C)	Boiling point (°C)
W	shiny grey	yes	3410	5930
X	orange-brown	no	–7	59
Y	shiny silver-coloured	yes	–39	357
Z	shiny silver-coloured	yes	1890	2482

Table B. Properties of elements.

Darshan looks at the data for element W. The element is shiny and it conducts electricity. The melting point and boiling point data show that element W is in the solid state at room temperature.

Darshan makes a conclusion:

Element W has the properties of a typical metal, so element W is a metal.

Observations that do not fit a pattern

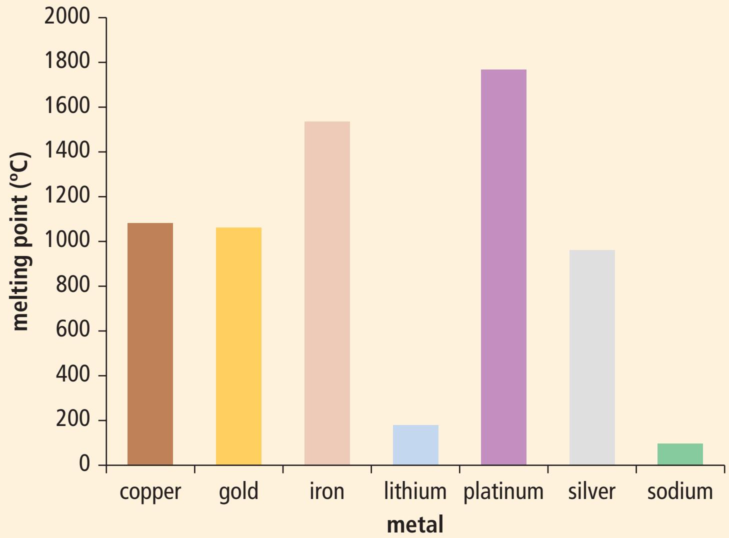
Bar charts

Peni collects data from the Internet on the melting point of different metals. She wants to identify metals that have melting points that are not typical of metals.

Peni examines the data on the bar chart. She notices that two metals have melting points that are much lower than those of the other metals.

Peni makes a conclusion:

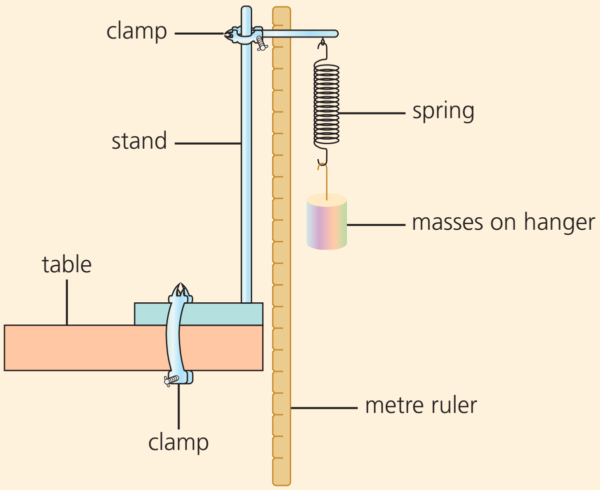
Lithium and sodium have melting points that are lower than those of the other metals on the bar chart.

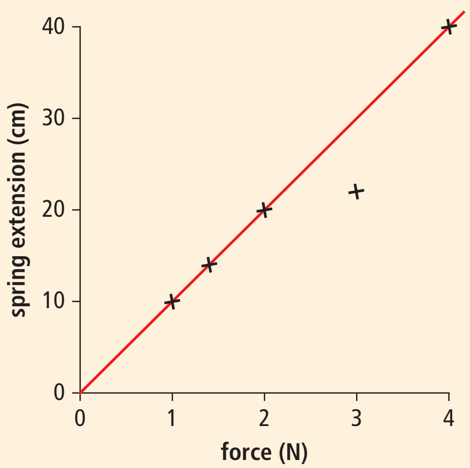


Line graphs

Grace investigates a metal spring. She hangs weights on the spring. She measures the **extension** of the spring (its increase in length) when she hangs different weights from it. Grace plots her results and draws a line of best fit.

Grace examines the graph, and notices that one result does not fit the pattern. She decides to measure the extension at this weight again, to see if she might have made a mistake in her investigation.





Grace repeats the test for the weight that gave the odd result. The value for extension is higher than before. It now fits the pattern. Grace decides she must have made a mistake the first time she did this test, and decides not to use the data she collected at first.

Q

1. Use the data in Table A to identify the metal in the table that is the least good conductor of heat.
2. Use the data in Table B to decide whether elements X, Y, and Z are metals or non-metals. Give reasons for your decisions.
3. Describe the pattern shown on the line graph above.
4. Write a second conclusion for the data on the bar chart that is different from the one written by Peni at the top of the page.

!

- You can make conclusions from results presented in different ways.
- If a result does not fit the pattern, repeat the test to see if you have made a mistake.

Extension

2.5 Metal alloys

Objectives

- Know what alloys are
- Give examples of alloys and their properties and uses
- Explain why alloys have different properties from the elements in them

What is an alloy?

Aeroplanes are mainly metal. The lighter an aeroplane, the less fuel it needs. So engineers chose low density metals for aeroplane bodies.

Most aeroplane bodies contain lots of aluminium, but they are not made of pure aluminium. The pure metal is too weak. Aluminium mixed with small amounts of other metals, such as zinc, copper, or magnesium, is stronger.

A mixture of metals is an **alloy**. Some alloys also include a non-metal element. Many alloys are harder or stronger than the elements that are in them.

Material	Composition	Density (g/cm^3)	Relative hardness	Strength when pulled (MPa)
Pure aluminium	100% aluminium	2.7	23	8
Aluminium alloy 7075	90% aluminium 6% zinc 2% magnesium 1% copper 1% other metals	2.8	150	572

Table A. Properties of aluminium and an aluminium alloy.

Scientists investigate different mixtures to make alloys with perfect properties for particular uses.

The cables of the New Aswan Bridge, Egypt, are made from steel.

Steel – a vital alloy

Steel makes many things – from stunning structures to tiny components.

There are many types of steel. Steels are alloys of iron. Pure iron is very soft and bendy, so it is not very useful. In steel, iron is mixed with small amounts of a non-metal, carbon, and sometimes other metals. The other elements change the properties of iron and make it more useful.

Steel and wood jewellery from Bali, Indonesia.

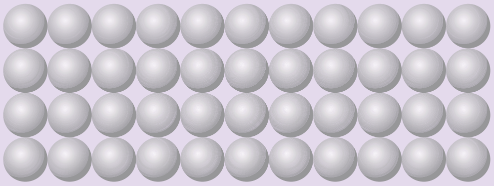
Name of alloy	Other elements	Properties	Uses
low carbon steel	carbon	strong easily shaped	bridges, buildings, ships, vehicles
manganese steel	manganese carbon	hard tough	mining equipment, railway points
stainless steel	chromium nickel carbon	does not rust	knives and forks, surgical instruments

Table B. Alloys of iron.

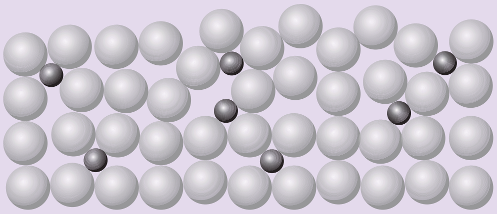
Explaining alloy properties

In a pure metal, the particles are arranged in layers. The diagram shows part of the particle arrangement in pure iron. The layers of particles slide over each other easily. This means that pure iron is soft and weak.

Particles of iron and the other elements in steel have different sizes. In steel, particles of the other elements get between the iron particles. The layers of iron particles can no longer slide over each other easily. This makes steel harder and stronger than pure iron.



Particles in iron.



Particles in steel.

Bronze

Bronze is an alloy of copper and tin. It was first used about six thousand years ago to make tools and weapons. Bronze is harder and more durable than stone, which was used before.

Modern motors with bronze bearings do not need oiling. This is because bronze has low friction with other metals.

Seven hundred years ago people of the kingdom of Benin (now in Nigeria) made bronze sculptures.

People from Himachal Pradesh, India, made the bronze bowl below about 2000 years ago.

Bronze head made in the kingdom of Benin, 16th century.

Indian bronze bowl from 2000 years ago.

Q

1. Explain what an alloy is.
2. Use Table A to compare the properties of pure aluminium and an aluminium alloy.
3. Use Table B to describe how the uses of three iron alloys are related to their properties.
4. Use words and diagrams to explain why iron has different properties from its alloys.

!

- Most alloys are mixtures of metals.
- Alloys have different properties from their elements, making them more useful.

2.6 Material properties

Objective

- Describe everyday materials and their physical properties

Fit for purpose

The objects we use are made from many different materials, including wood, glass, and polythene. The materials chosen to make an object must be suitable for their purpose.

For example, a desk must be stiff and strong. Its surface must be hard. Wood has these physical properties. It makes excellent tables.

This water container is made from clay. A small amount of water is absorbed by the container. This evaporates from the surface, which helps to keep the water inside the container cool.

This woman is wearing clothes made from cotton. Cotton fabric is soft and flexible. Water and air can pass through its small holes, helping to keep the wearer cool.

The nurse is wearing gloves made from rubber. Rubber is flexible and waterproof. It has no holes. Water, blood, and germs cannot pass through it.

Sisal is strong when pulled. It makes useful ropes.

Most windows are made from glass. Glass is transparent, so you can see through it. Unfortunately glass is also brittle – it breaks easily.

This bottle is made from plastic. The plastic is flexible, transparent, and tough.

Material properties

Scientists consider many physical properties when choosing materials for particular purposes. They choose materials which are suitable for their purpose and which are not too expensive.

Strength

Scientists ask questions about strength:

- With what size force can you pull a material before it breaks?
- What size force will squash the material?

Stiffness, flexibility, and brittleness

A stiff material is one that is difficult to bend. A thick piece of wood is stiff.

Flexible materials bend easily. Thin pieces of aluminium are flexible, so are thin pieces of wood from some tree species.

A **brittle** material breaks easily when you bend or hit it. Glass is brittle.

This fence is made from flexible willow wood.

Hardness

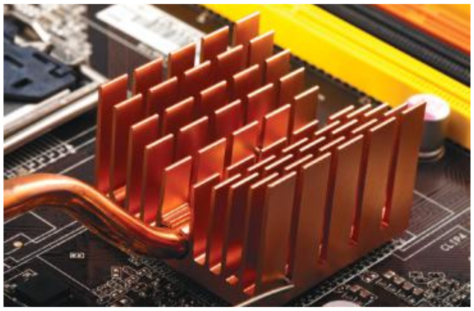
You can scratch a soft material, such as leather, with your fingernail. Diamond is a very hard material. You cannot scratch it – even with a steel knife. This means that diamonds in jewellery cannot be damaged by scratching.

Diamonds are hard and cannot be damaged by scratching.

Conducting heat

Metals like copper and aluminium are good conductors of heat. They are used to transfer heat away from processing units in computers, to stop them overheating.

Materials that do not allow heat to pass through them are heat insulators. Wool and fur are good heat insulators.



Copper heat sinks stop computers overheating.

Fur prevents this yak from losing too much heat.

Conducting electricity

Electricity passes easily through good conductors of electricity, such as copper and aluminium. These materials are used for electric cables.

Electricity cannot pass through plastics. Plastics are insulators.

Water absorption

A waterproof material, such as polythene, does not allow water through it. A substance is absorbent if it has tiny holes that water can seep into.

Q

1. Explain why cotton is a suitable material for making clothes.
2. Identify a material used to make rope, and explain why it is suitable for this purpose.
3. Suggest the physical properties a material for making a football needs to have.

!

- The physical properties of a material determine its uses.

Extension 2.7

Polymers

Objective

- Understand what polymers are and how they are used

Plastics everywhere

Look around you. How many things are made of plastics? Imagine life without plastics. Your great-great-grandparents probably did live without most of them – plastics only started to be widely used in the 1930s.

These buckets, baskets, and trays are all made from plastics.

Most of the materials we call plastics are made from polymers. **Polymers** are substances that have very long particles.

The properties of poly(ethene) make it perfect for bags and bottles.

Inside poly(ethene)

Poly(ethene), also known as polythene, is an important polymer. Its physical properties make it useful. It is strong, tough, and waterproof. It is an electrical insulator. Poly(ethene) can be flexible, too.

Poly(ethene) particles are very long. They are made by joining up particles of two elements – carbon and hydrogen.

The long particles explain the physical properties of poly(ethene):

- It is strong because it is difficult to break up its particles.
- It is flexible because its particles can slide over each other easily.

Poly(propene) rope.

More polymers

There are thousands of polymers, each with their own properties and uses.

Poly(propene)

Poly(propene) is strong. It is not damaged by high temperatures. It is flexible, and you can bend it many times without it breaking. This means that poly(propene) is useful for making many things, including:

- ropes
- underground water pipes
- hinges for flip-top bottles.

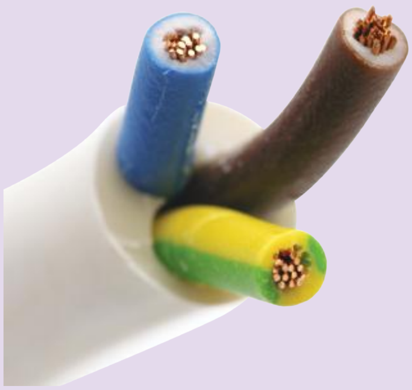
A flip-top plastic bottle.

Poly(chloroethene)

Poly(chloroethene) is better known as poly(vinyl chloride) or PVC. It is another polymer with useful physical properties. PVC is flexible and waterproof. It does not conduct electricity.

PVC is used to make:

- underground water pipes
- the insulation on electric cables
- waterproof clothes.



PVC is an electrical insulator.

PVC is waterproof.

Natural polymers

Poly(ethene), poly(propene), and PVC are **synthetic polymers**. They are made by people and machines in factories and science laboratories.

We also use **natural polymers**. Fibres like cotton, silk, and wool are made up of polymers. So is wood. Natural polymers are made by plants and animals.

Cotton plants produce cotton fibre.

Silk worms produce silk.

Q

1. Explain what a polymer is.
2. Name six polymers.
3. Explain why poly(ethene) is strong.
4. Give three uses of PVC, and explain why its properties make it suitable for these uses.

!

- The physical properties of a polymer determine its uses.

Review 2.8

1 The photograph shows some gold coins. They were made about 800 years ago in India.

The list gives some physical properties of gold.

It is a good conductor of electricity.
It melts at 1063 °C.
It is always shiny.
It is a good conductor of heat.
It is yellow.

a Which one of the properties in the list best shows that gold is solid at 20 °C? [1]

b Identify two properties in the list that are typical of all metals. [1]

c Which one of the properties in the list best explains why gold was used to make coins? [1]

d Which two of the properties in the list best explain why gold is used to make connectors in some electrical devices? [1]

2 The table shows the physical properties of four elements. Each element is represented by a letter.

Element	Appearance at 25 °C	Does it conduct electricity?	Melting point (°C)
A	green	no	–101
B	shiny silver-coloured	yes	961
C	shiny grey	yes	1535
D	dull yellow	no	113

a Give the letter of the element in the table that has the highest melting point. [1]

b Give the letters of the elements in the table that are non-metals. Explain your choices. [1]

3 Copy and complete the following sentences using words from the list. You may use them once, more than once, or not at all.

a good conductor of heat **strong**
a good conductor of electricity **sonorous**

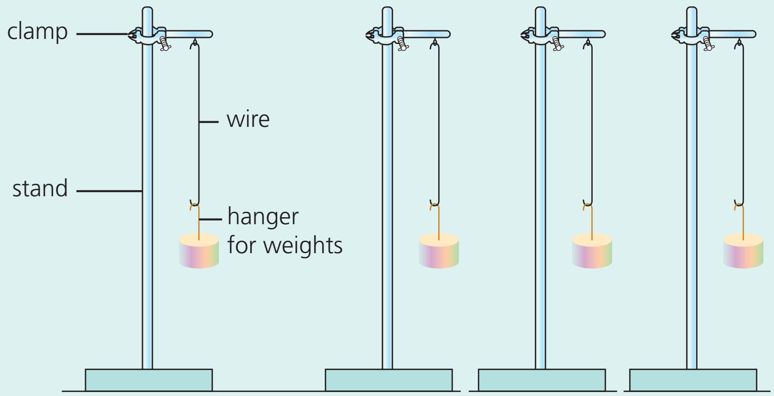
a Aluminium is used to make cooking pans because it is _______. [1]

b Copper is used in the cable of a lamp because it is _______. [1]

c Copper can be used to make bells because it is _______. [1]

d Iron is used to make cars because it is _______. [1]

4 A student wants to compare the strength of four substances. She sets up the apparatus below. She adds weights until the wires break.



a Identify the variable the student changes. [1]

b Suggest two variables the student should control to make the test fair. [2]

c The student's results are in the table.

Substance	Mass at which wire broke (kg)
copper	11
tungsten	8
stainless steel	5
aluminium alloy	3

i Which substance makes the strongest wires? [1]

ii Display the results on a bar chart. [3]

5 The list gives some properties materials can have.

waterproof	**flexible**	**low density**
transparent	**rusts easily**	**strong**
brittle	**absorbent**	

a Which two physical properties in the list make glass suitable for windows? [2]

b Which two physical properties in the list make rubber suitable for nurses' gloves? [2]

c Which three physical properties in the list make plastics such as poly(propene) suitable for making buckets? [3]

d Which two physical properties in the list make iron suitable for making buckets? [2]

e Which one property in the list is vital for a material used to make a baby's nappy? [1]

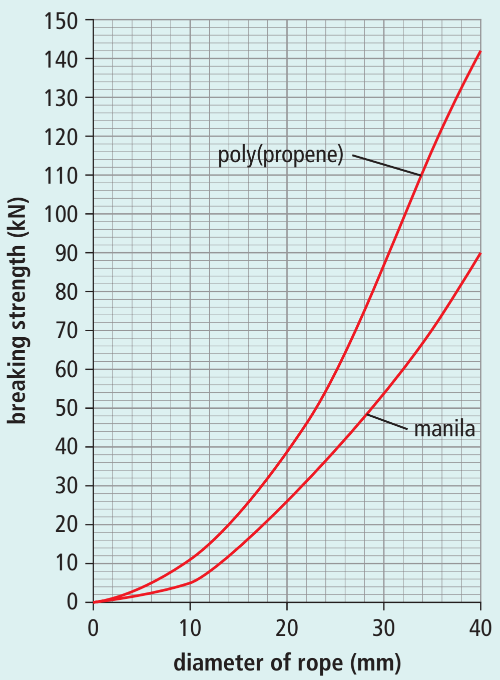
6 The table shows the physical properties of two materials that are used to make ropes.
Manila fibre is obtained from a plant.
Poly(propene) is made from substances obtained from oil.

Material	Durability	Breaking strength for 10 mm rope (N)	Flexibility
manila fibre	rots slowly	5400	very flexible
poly-(propene)	does not rot	10 800	very flexible

a Identify two advantages of poly(propene) ropes compared to manila ropes. [2]

b Suggest one advantage of making ropes from manila. [1]

c The graph below shows how the strengths of manila and poly(propene) ropes change as rope diameter increases.



i Use the graph to find the strength of manila rope of diameter 30 mm. [1]

ii Use the graph to predict the diameter of poly(propene) rope that has a strength of 120 kN. [1]

iii Use the graph to describe how the strength of manila rope changes as its diameter increases. [1]

iv Use the graph to work out which is stronger – 30 mm manila rope or 20 mm poly(propene) rope. [1]

7 The table gives data about three materials that can be used to build houses.

Material	Strength when compressed (MPa)	Conductivity of heat (W/mK)
limestone	60	1.3
concrete	60	1.7
wood	15	0.1

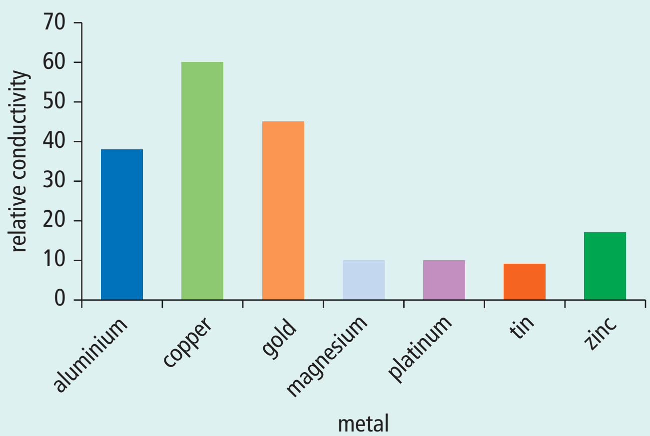
a Which of the materials in the table is the weakest when compressed? [1]

b Which of the materials in the table is the best conductor of heat? [1]

c A person wants to build a house which will feel cool inside. He chooses to build his house from wood. Explain why. [1]

d Use the data in the table to suggest one advantage of building a house from limestone compared to wood. [1]

8 The bar chart below compares how well different metals conduct electricity.



a Explain why the data is presented in a bar chart, not in a line graph. [1]

b List the metals in the bar chart in order of increasing conductivity (lowest conductivity first). [2]

3.1 Acids and alkalis

Objectives

- Give examples of acids and alkalis
- Compare the properties of acids and alkalis
- Make conclusions from data

Everyday acids

Lemons, limes, and vinegar taste sour. Why? They all contain **acids**.

Acids are vital to life. Hydrochloric acid in your stomach helps digest food. Ascorbic acid – vitamin C – in fruit keeps your skin healthy and helps to make bones. You need omega-3 fatty acids from oily fish or soya beans to help defend your body against disease.

Acids have other uses. Vinegar is a solution of ethanoic acid in water. It is used to preserve fruit and vegetables in pickles. Fizzy drinks contain acids to flavour and preserve them.

Natural acids can also be a nuisance. Methanoic acid helps to make bee and ant stings painful. Acids make sweat smelly, too.

Vinegar preserves fruit and vegetables in pickles.

Laboratory acids

At school you might use sulfuric acid, hydrochloric acid, and nitric acid. These acids are **corrosive**, even when mixed with lots of water. This means they destroy living tissue, so they will burn your skin and eyes.

You must wear eye protection when using acids in the lab and make sure they do not get on your skin.

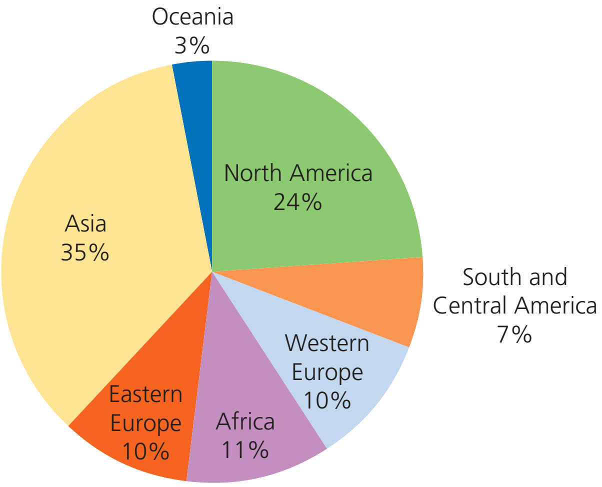
This symbol shows that a chemical is corrosive. Wear eye protection and take care not to get the chemical on your skin.

Making conclusions from data in charts

Sulfuric acid is very important. It is used to make fertilizers, detergents, dyes, medicines, insecticides, paints, and batteries.

Worldwide, factories make over 180 million tonnes of sulfuric acid each year. This pie chart shows the relative amounts of sulfuric acid produced in different areas of the world. More sulfuric acid is produced in Asia than in any of the other areas.

Percentage of sulfuric acid produced in different regions of the world

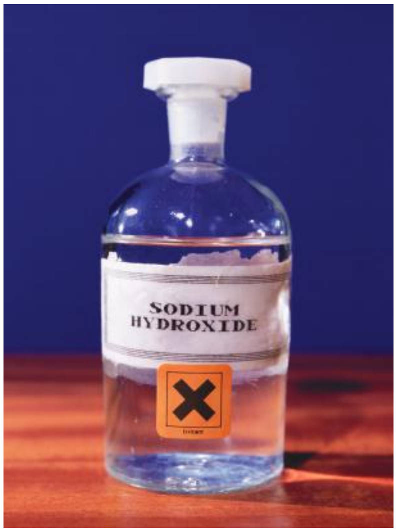


Alkalis

Alkalis are the chemical opposite of acids. They often feel soapy, although you should never touch an alkali unless you have been told it is safe to do so. Toothpaste and washing powder make alkaline solutions when mixed with water. Seawater is also slightly alkaline.

Sodium hydroxide solution is an important alkali. It is used to make paper and detergents. It also used to produce aluminium metal.

Many alkaline solutions are extremely corrosive. A small splash of sodium hydroxide on your skin gives a nasty blister. If sodium hydroxide gets in your eye, it may cause blindness. You must always wear eye protection when using alkalis or acids in the lab.



Sodium hydroxide is an important alkali.

Some cleaning fluids contain alkaline substances.

Discovering acids and alkalis

Jabir Ibn Hayyan was an important scientist. He worked in the area now known as Iraq around 1200 years ago.

Jabir Ibn Hayyan discovered how to make sulfuric acid, nitric acid, and hydrochloric acid. He was probably the first person to use the word 'alkali'. Jabir wrote more than 100 books about his findings, which scientists found useful for hundreds of years.

Jabir Ibn Hayyan

Q

1. Name six acids.
2. Give one hazard of using sodium hydroxide, and state how to reduce the risks from this hazard.
3. Give one property that is typical of acids, and one property that is typical of alkalis.
4. Use data from the pie chart opposite to answer this question:
   a. Name the area that produces the least sulfuric acid.
   b. Give the total percentage of sulfuric acid produced in Africa, Asia, and South and Central America.

!

- Acids include sulfuric acid, hydrochloric acid, and nitric acid.
- Alkalis include sodium hydroxide.
- Acids and alkalis have many uses.
- Acids and alkalis can be corrosive.

3.2 The pH scale and indicators

Objectives

- Know the pH of acidic, alkaline, and neutral solutions
- Use indicators to measure pH
- Choose suitable apparatus

Litmus indicator is red in acidic solution and blue in alkaline solution.

The pH scale

The pH scale shows how acidic or alkaline a solution is:

- The pH of an acid is less than 7. The lower the pH, the more acidic the solution.
- The pH of an alkali is more than 7. The higher the pH, the more alkaline the solution.
- Some solutions are neither acidic nor alkaline. They are neutral. Their pH is 7. Pure water has a pH of 7.

Using indicators

Litmus indicator shows whether a solution is acidic or alkaline. You can use it as a solution, or soaked into paper.

You can use **Universal Indicator** to find the pH of a solution. When you add it to a solution it changes to one of the colours on the pH scale shown below. The colour shows the pH of the solution.

The colours of Universal Indicator solution from pH 0 (left) to pH 14 (right).

Choosing and using apparatus

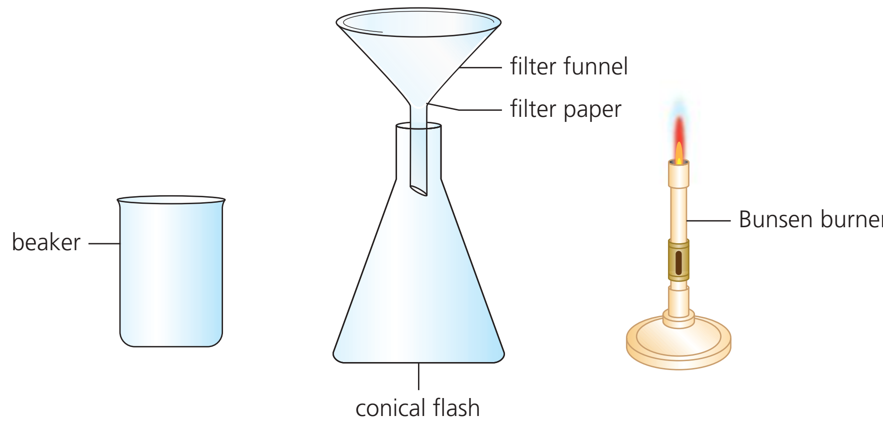
Some plants, like hibiscus flowers and red cabbage, contain chemicals that change colour when they are added to solutions of different pH. This means you can make your own indicators.

Making an indicator

Femi makes a hibiscus flower indicator at home. She adds hibiscus flowers to warm water in a cooking pot. She then pours the mixture through a colander and collects the solution in a glass.

Adamma makes a hibiscus flower indicator in a science laboratory. She adds hibiscus flowers to water in a beaker and heats the mixture with a Bunsen burner. She pours the mixture through filter paper and collects the solution in a conical flask.

Femi's apparatus.



Adamma's apparatus.

Both Femi and Adamma have chosen suitable apparatus, since both made a usable indicator.

Testing the indicator

Femi placed some acid on a green plate and added hibiscus indicator. She repeated the test with an alkali instead of the acid. She wrote down the colours she saw.

Adamma poured some acid into a test tube and added hibiscus indicator. She repeated the test with an alkali. She wrote down the colours she saw.

In this part of the experiment, Femi's apparatus was not suitable. She could not see the colours properly on the green plate. Adamma made a better choice of apparatus.

Concentrated or dilute?

The lorry is carrying ethanoic acid. The acid could give you terrible burns. But ethanoic acid in vinegar is safe to eat in pickles and chutneys. What's the difference?

In vinegar, ethanoic acid is mixed with a large amount of water. This is a **dilute** solution. But the ethanoic acid in the lorry is mixed with very little water, so it is a **concentrated** solution.

Concentrated acids and alkalis are more corrosive than dilute ones.

Q

1. Give the colours of litmus indicator in acidic and alkaline solutions.
2. A solution has a pH of 8. Is it acidic or alkaline?
3. Which is more acidic, a solution of pH 6 or a solution of pH 4?
4. Look at the section above on *Testing the indicator*. Suggest some apparatus that Femi could use at home to test her indicator. Explain why Adamma's apparatus is better than a green plate.

!

- An acid has a pH of less than 7.
- An alkali has a pH of more than 7.
- A neutral solution has a pH of 7.
- The colour of Universal Indicator can be used to estimate the pH of a solution.

3.3 Neutralisation

Objectives

- Understand what neutralisation is
- Give examples of applications of neutralisation

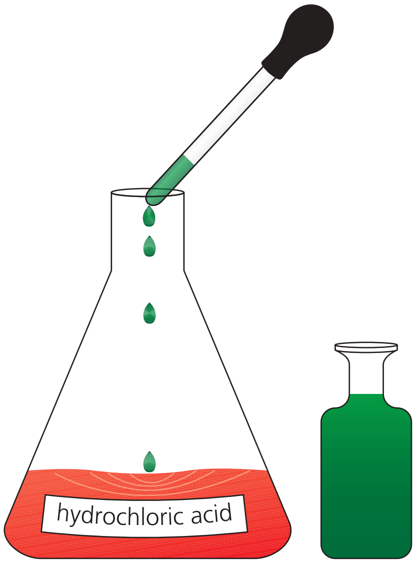
Neutralisation

A bee stings Sudi. It hurts! Sudi rubs toothpaste on the sting. It feels a bit better. Toothpaste is alkaline. The alkali cancels out – **neutralises** – some of the acid in the sting. This process is **neutralisation**.

Bee stings are acidic.

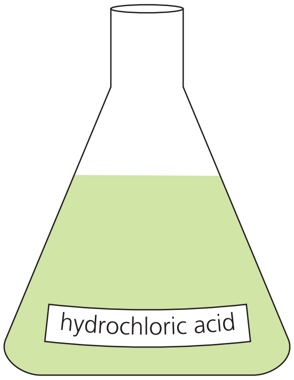
Neutralisation in the laboratory

You can do neutralisation reactions in the laboratory. Hasina has 100 cm^3 of hydrochloric acid. She wants to find the volume of sodium hydroxide solution needed to neutralise the acid.



The Universal Indicator is red. This shows that the solution is acidic.

The Universal Indicator is orange. This shows that the pH of the solution has increased. The sodium hydroxide has neutralised some of the hydrochloric acid.



The Universal Indicator is light green. This shows that the pH of the solution is 7. The solution is neutral. The sodium hydroxide has neutralised all the hydrochloric acid.

To neutralise an acid you need to add the correct volume of alkali. The volume depends on how dilute or concentrated the solutions are.

Using neutralisation reactions

Soil pH

Some soils are more acidic or alkaline than others. Every plant has its favourite soil pH. Carrots grow well in soil of pH 6.0. Tea grows best in soil of pH 4.0 to 5.5. Date palms prefer pH 6.5 to 8.0.

The table shows the preferred soil pH of some vegetables.

Vegetable	Preferred soil pH
cabbage	6.0–7.0
onion	6.0–6.5
maize	5.5–7.0
sweet potato	5.0–6.0
tomato	5.5–6.8

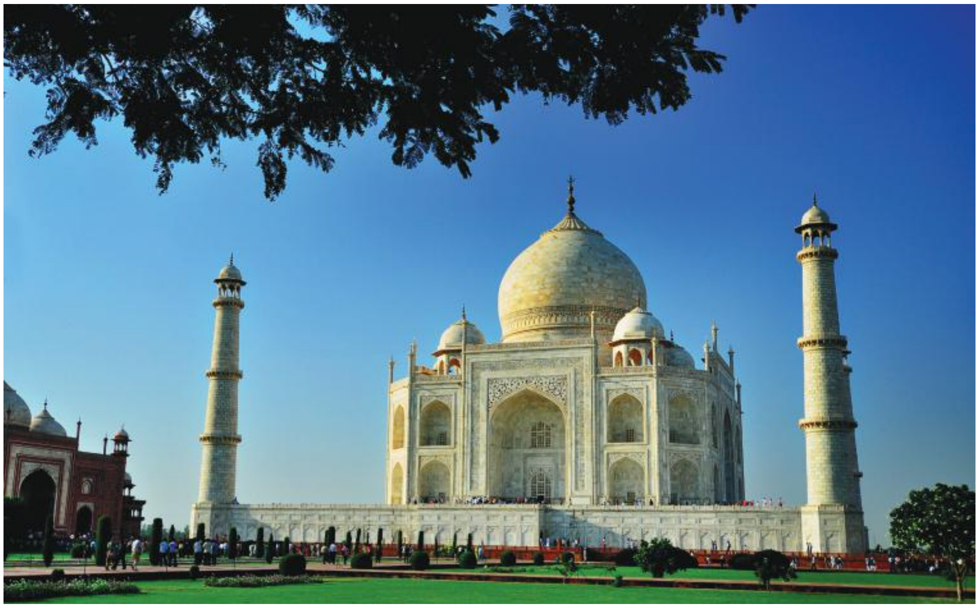
Zainab takes some soil from her garden. She mixes it with pure water. She adds Universal Indicator. The indicator shows that the soil is acidic – its pH is 5.0. The soil is suitable for sweet potatoes.

Zainab also wants to grow cabbage and onions. But they grow best on soils of higher pH. Zainab adds an alkali to the soil in one part of the garden. This neutralises some of the acid. The soil pH increases. Zainab can now grow cabbage and onions.

Sweet potatoes grow best in soil of pH 5.0 – 6.0.

Acid rain

Scientists were worried about the Taj Mahal in India. The magnificent marble monument was being damaged by **acid rain**. Local factories polluted the air with acidic gases. The gases dissolved in rainwater, making the rain acidic.



Acid rain damaged the Taj Mahal.

The government has taken action. Now, nearby factories must neutralise any acidic gases they produce, or move away.

In the last century gases from burning coal in Europe made acid rain. The acidic rain fell over Europe and ran into rivers and lakes. Rivers and lakes became more acidic. Some animal and plant species could not survive.

Substances were added to lakes to neutralise the extra acid. Some power stations stopped releasing acidic gases into the air. By 2000 the water pH in many lakes had returned to normal.

Q

1. Explain what neutralisation is.
2. Ola has a solution of pH 9. Should he add acid or alkali to neutralise the solution?
3. Use the table on the opposite page to help you answer this question. Cabar measures the soil pH on her farm. Its pH is 8.0. Cabar wants to grow onions. What type of substance should she add to the soil so that its pH is suitable for growing onions?

!

- Neutralisation is the ‘cancelling out’ of an acid by an alkali, or of an alkali by an acid.
- Neutralisation changes soil pH.
- Acid rain damages some buildings and harms plants and animals that live in lakes.

Enquiry 3.4

Planning investigations and collecting evidence

Objective

- Understand how to plan an investigation, and collect and consider evidence

Neutralisation

Kali has stomach ache. He takes an indigestion tablet. The tablet contains a substance that neutralises the extra acid in his stomach. Kali feels better.

Kali saw three different types of indigestion tablet in the pharmacy. He wants to find out which type of tablet is best. He decides to investigate.

Read on to find out how Kali plans his investigation.

Suggesting ideas to test

Kali thinks of possible questions to investigate:

- *Which type of tablet is best?*
- *Which type of tablet causes the greatest increase in pH when added to stomach acid?*
- *Which type of tablet neutralises the most acid?*

Kali decides to answer the second question. He does not make a prediction since he has no scientific evidence to base it on.

Choosing variables

Kali identifies the variables in his investigation. He decides which to change, observe, and control.

- *Variable to change – type of tablet.*
- *Variable to observe and measure – pH change of stomach acid when I add a tablet to it.*
- *Variables to control to make the test fair:*
  - *type of acid to represent stomach acid*
  - *volume of acid*
  - *how concentrated or dilute the acid is.*

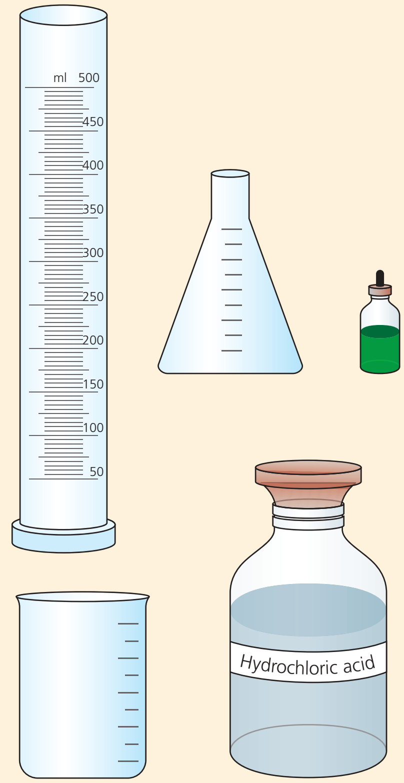
Collecting evidence

Kali chooses hydrochloric acid to represent stomach acid. He uses a measuring cylinder to measure equal volumes of acid for the three tests. A measuring cylinder measures smaller differences in volume than a beaker.

Kali pours the acid into a conical flask. He adds Universal Indicator. He uses a colour chart to find the acid pH.

Next, Kali adds a tablet to the acid. He measures the pH of the mixture, and records his results in a table.

Finally, Kali repeats the procedure for the other two types of tablet.



Apparatus for measuring the pH change when an indigestion tablet is added to an acid.

Considering evidence

Kali records his data.

Type of tablet	pH before adding tablet	pH after adding tablet	Change in pH
A	1	4	3
B	1	1	0
C	1	5	4

Kali looks at his results and thinks about his question. He writes a conclusion which includes a scientific explanation:

Tablet C caused the greatest increase in pH. This means that tablet C neutralised the most acid.

Observations that do not fit a pattern

Kali was surprised the pH did not change when he added tablet B to the acid. He thought he might have made a mistake. He repeated the test for tablet B three more times. His results are in the table.

Tablet B test number	pH before adding tablet	pH after adding tablet	Change in pH
1	1	1	0
2	1	4	3
3	1	4	3
4	1	4	3

Kali noticed that the result for test 1 was different from the others. He decided to ignore this result.

Q

1 Explain why Kali kept some variables constant in his investigation.

2 Why did Kali use a measuring cylinder to measure out equal volumes of acid, and not a beaker?

3 Suggest why Kali chose to answer the second question in the section *Suggesting ideas to test*.

!

- Planning an investigation can involve asking questions, considering variables, and choosing apparatus.
- If a result does not fit the pattern, repeat the test.

Review 3.5

1 Copy and complete the sentences using phrases from the list. You may use them once, more than once, or not at all.

more than **equal to** **less than**

The pH of an acid is _______ 7. The pH of an alkali is _______ 7. The pH of a neutral solution is _______7. [3]

2 **a** Copy and complete the table to show whether each mixture is acidic, alkaline, or neutral.

Mixture	pH	Acidic, alkaline, or neutral?
orange juice	3	
cola drink	2	
sweat	5	
indigestion medicine	9	

[4]

b Name one substance in the table above that could be used to neutralise orange juice. [1]

c Name one substance in the table that could be used to neutralise the indigestion medicine. [1]

3 This question is about litmus indicator.

a Copy and complete the table below.

Type of solution	Colour of litmus indicator
acidic	
alkaline	

[2]

b A student has 100 cm^3 of an acid. She adds a few drops of litmus indicator. The student then adds 500 cm^3 of an alkaline solution of the same concentration as the acid. Describe the colour changes he would observe. [2]

4 Read the information in the box. Then answer the questions below.

> Your blood is slightly alkaline. Its pH is always 7.4. You would be very ill if your blood pH was higher than 7.6 or lower than 7.2.
> The pH of your urine changes to help adjust blood pH:
> ~ If your blood gets too acidic, extra acid comes out in your urine. You urine pH gets lower.
> ~ If your blood gets too alkaline, extra alkali comes out in your urine. You urine pH gets higher.

a Explain why your urine pH gets lower when your blood is too acidic. [1]

b What happens to your urine pH if your blood is too alkaline? Explain why. [1]

c A hospital patient has a blood pH of 7.5. Explain how her body tried to get the blood pH back to normal. [1]

5 The table gives the preferred soil pH of some plants.

Plant	Preferred soil pH
pineapple	4.5 to 5.5
banana	5.5 to 6.5
sugar cane	5.5 to 6.5
maize	5.5 to 7.0
cassava	4.5 to 7.5

a Name the one crop in the table that can grow well in a slightly alkaline soil. [1]

b A farmer tests the soil pH on her farm. Its pH is 5.0. Suggest two crops she could try growing. [2]

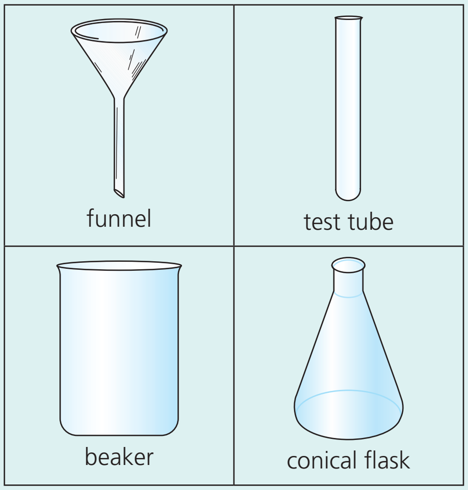
c A farmer knows her soil is acidic, but does not know the soil pH. Suggest one crop she could try growing. [1]

d The soil pH on another farm is 7.0.

i Suggest two crops that might grow well on this soil. [2]

ii The farmer on this farm wants to grow bananas. What type of substance should he add to his soil? [1]

6 A student wants to make an indicator from red cabbage. The apparatus available to the student is listed and pictured below.



a The student first heats a mixture of pure water and chopped cabbage. Name the best apparatus in which to do this. [1]

b Next the student filters the mixture. She wants to keep the solution. Name the best two pieces of apparatus for this stage. [2]

c The student adds her indicator to small amounts of acid and alkali to observe its colours in the two solutions. Name the best apparatus in which to do this. [1]

7 Table A shows the pH that some animals can live in. The animals can only survive at pH that are shaded grey. Table B shows how the pH of two lakes changed over time.

Table A

Animal	Water pH the animal can live in							
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
trout								
salmon								
eel								
frog								
snail								
mayfly								

Table B

Name of lake	pH of lake water			
	1960	1970	1990	2001
Lake X	-	-	5.0	6.0
Lake Y	6.0	4.5	-	-

a What was the pH of Lake Y in 1960? [1]

b What happened to the acidity of Lake Y between 1960 and 1970? [1]

c Name two animals that might have lived in Lake Y in 1960. [2]

d Name one animal that might have lived in Lake Y in 1970. [1]

e A biologist found a large number of snails in Lake Y in 2010. Suggest what might have happened to the lake pH to make this possible. [1]

f **i** A biologist found no mayflies in Lake X in 1990. Suggest one possible reason for this. [1]

ii The biologist looked for mayflies in Lake X in 2001. Do you think she found any? Explain your answer. [1]

8 A student investigates the question below:

How does the volume of acid needed to neutralise an alkali depend on the concentration of the alkali?

The concentration of a solution is the mass of substance dissolved in 1 litre of the solution.

The student writes down what she plans to do.

~ Take 50 cm^3 of alkaline solution.
~ Add Universal Indicator.
~ Add acid until the indicator shows the solution is neutral.
~ Write down the volume of acid used.
~ Repeat with alkaline solution of different concentrations.

a The student uses a measuring cylinder, not a beaker, to measure the volume of acid added. Suggest why. [1]

b Copy and complete the table. Use the phrases below.

volume of acid **concentration of acid**
concentration of alkali **volume of alkali**
type of indicator

Variable to change	
Variable to observe	
Control variables	1. 2. 3.

[5]

c The student's results are in the table below.

Concentration of alkali (g/dm^3)	Volume of acid (cm^3)
0.1	10
0.2	20
0.3	30
0.4	50
0.5	50

i Plot the results on a graph. [3]

ii Draw a line of best fit. [1]

iii Draw a circle around the one odd result on your graph. [1]

4.1 The structure of the Earth

The ground beneath your feet

Imagine you could dig a hole more than 6000 km deep, to the centre of the Earth. What would you find?

Scientists have been curious about the structure of the Earth for many years. They made observations and collected data, and thought carefully about them. They created **scientific models** to explain their observations.

A scientific model is an idea that explains observations. It can be used to make predictions.

Objectives

- Describe a model for the Earth's structure
- Explain how we know about the Earth's structure

Early models of the structure of the Earth

Flat Earth model

For many years, people thought the Earth was flat. They based this idea on their observations.

Gradually, observations made people think that the flat Earth model might be wrong. Sailors noticed that ships appear to sink as they go over the horizon.

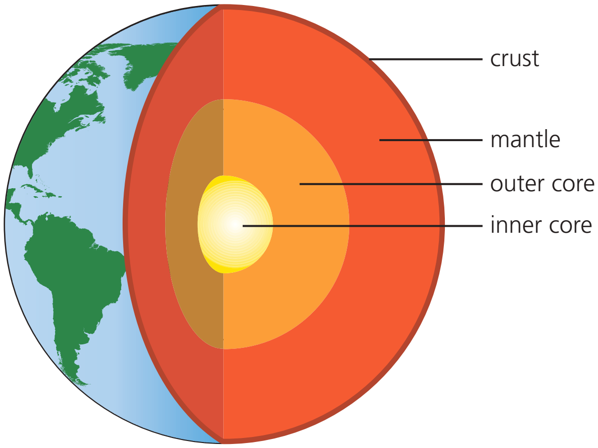
Aristotle lived more than 2000 years ago. He saw that the shadow of the Earth on the Moon is round. These observations led to a new model of the Earth, as a sphere.

Observations from space give further evidence that the Earth is a sphere.

Ships appear to sink as they go over the horizon.

The hollow Earth model

About 300 years ago Edmond Halley suggested a new model of the Earth. He said the Earth consisted of three hollow shells separated by air. Halley created his model to explain some unusual compass readings.



The modern model for the structure of the Earth.

The modern model of the structure of the Earth

Scientists used many observations and data to create the modern model of the structure of the Earth.

The model states that the Earth is made up of several layers:

- a solid **crust** made of different types of rock
- the **mantle**, which goes down almost halfway to the centre of the Earth. It is solid but can flow very slowly.
- the liquid **outer core**, made up mainly of iron and nickel
- the solid **inner core**, also mainly iron and nickel.

How do we know about the structure of the Earth?

Observations and data from many scientists have contributed to our understanding of the Earth. Scientists studied rocks on the surface and under oceans. They examined rocks brought to the surface by volcanoes.

Shock waves from earthquakes also provided evidence. In the 1930s Inge Lehmann examined shock wave patterns. She couldn't explain them using the model of the time – that the Earth's core was the same all the way through. She created a new model – that the core consists of two parts. Inge Lehmann had discovered the solid inner core.

Inge Lehmann discovered the inner core.

Hotter and hotter

Temperatures increase from crust to core. The core, 6000 km below the surface, is very hot. It may be hotter than the surface of the Sun.

Some of the deepest mines in the world are in South Africa. They are nearly 4 km deep. At these depths the rock temperature is about 60 °C. The air is cooled so that miners can do their work.

Deep South African gold mines are very hot.

Q

1. Name the layers of the Earth, starting from the inside.
2. Identify two pieces of evidence that suggest the Earth is spherical.
3. Outline the evidence suggesting that the Earth has a solid inner core.

!

- The Earth consists of the crust, mantle, outer core, and inner core.
- Temperature increases from the crust towards the core.

4.2 Igneous rock

Objectives

- Describe the properties of igneous rocks
- Give examples of igneous rocks
- Explain how igneous rocks formed
- Link igneous rock properties to their uses

The Earth's crust

Think about the things you've used today. Where did they all come from? The answer is the Earth's crust, the air, and the oceans.

The Earth's crust is made up of different types of rock. We use some types of rock just as they are. We extract metals from other rock types. We process some rock types to make cement and other building materials.

Grouping rocks

The pictures show three types of rock. They have very different properties.

Basalt, an igneous rock.

Limestone, a sedimentary rock.

Marble, a metamorphic rock.

There are many different types of rock. Scientists classify rocks into three groups:

- igneous rocks
- sedimentary rocks
- metamorphic rocks.

Igneous rocks

What do the structures below have in common?

The Giant's Causeway in Northern Ireland was formed from basalt.

The Pakistan Monument in Islamabad, completed in 2007.

This statue of an Egyptian queen, Hatshepsut, is 3500 years old.

Both structures are made from **granite**. Granite is an example of an **igneous rock**. Igneous rocks are made when **magma** (liquid rock) cools and solidifies.

Granite consists of interlocking **crystals**, strongly joined together. The crystals are quite big – you can see them easily. Each crystal is made of one substance.

Another igneous rock is **basalt**, which makes up much of the seabed.

Properties of igneous rocks

Igneous rocks are hard and durable. The rocks that originally surrounded these granite boulders on Belitung Island have been worn away, but the granite remains.

Most igneous rocks are also **non-porous** – water does not soak into them. This is because there are no gaps between their interlocking crystals.

Granite boulders on Belitung Island, Indonesia.

Using igneous rocks

The properties of igneous rocks explain their uses.

Basalt is hard and durable. It is used as railway ballast.

This sculpture is made from an igneous rock called gabbro. It is hard, durable, and attractive.

Quartz consists of a single mineral, silicon dioxide.

Minerals

Substances that exist naturally as crystals are called **minerals**. Most rocks are a mixture of minerals. Minerals also occur on their own.

Explaining crystal size

Basalt forms when runny liquid rock pours out of volcanoes and cools quickly, often under the sea. As the liquid cools, crystals grow as the particles arrange themselves in patterns. When all the particles are arranged in crystals, there is no liquid rock left. It has all become solid basalt.

Basalt's crystals are tiny. You need a magnifying glass to see them. The crystals are small because the liquid rock cooled and solidified in just a few weeks.

Granite forms when liquid rock cools underground. The cooling takes longer, so its particles have more time to arrange themselves. The crystals grow bigger.

Granite is a mixture of minerals. This sample includes quartz (grey crystals), calcium feldspar (white crystals), biotite (black crystals), and potassium feldspar (pink crystals).

Q

1. Describe the properties of a typical igneous rock.
2. What is a mineral?
3. Explain why you can often see different colours in a lump of granite.
4. Basalt has smaller crystals than granite. Explain why.

!

- There are three types of rock: igneous, sedimentary, and metamorphic.
- Igneous rocks are hard, durable, and non-porous.
- Igneous rocks formed from liquid rocks.
- Rocks that cooled quickly have small crystals.

4.3 Sedimentary rocks

Objectives

- Describe sedimentary rock properties
- Identify and name sedimentary rocks

Sedimentary rock properties

Limestone is a typical sedimentary rock. Sedimentary rocks are less hard than most igneous rocks. This means it is easier to scratch them.

Most sedimentary rocks are **porous**. You can find out if a rock is porous by dropping water onto it. If the water soaks in, the rock is porous. If the water does not soak in, the rock is non-porous.

The structure of a sedimentary rock explains its properties. They are made of **grains**. The grains are held together less strongly than the crystals in igneous rocks. There are small spaces between the grains. Gases (like air) or liquids (like water) fill the spaces.

Identifying sedimentary rocks

You can identify sedimentary rocks by doing these tests:

- Look at the rock through a hand lens or magnifying glass. Sedimentary rocks have separate grains with spaces between them.
- Place a few drops of water on the rock. Sedimentary rocks are porous, so the water will soak in.
- Place the rock in a beaker of water. If you see bubbles, the rock must include air spaces. It is probably a sedimentary rock.
- Try scratching the rock. If you can scratch it with your fingernail or an iron nail it is quite soft. It is likely to be a sedimentary rock.

India Gate, in New Delhi, India, is made of granite and sandstone.

Brick making in Rwanda.

Different sedimentary rocks

Different types of sediment make different types of rock. Each rock type has its own properties and uses.

Sandstone

Sandstone is a hard sedimentary rock. This means it makes a good building material. Its medium-sized grains are made of the mineral quartz. Other minerals cement the grains together.

Claystone and mudstone

Claystone and mudstone have tiny grains. They were squashed together by the weight of the layers above them.

It is easy to mould wet clay into different shapes. Bricks and pottery are moulded from wet clay. They are then fired to make them hard.

Limestone

Limestone is a useful building material. It was made from the remains of living things. Billions of dead shellfish piled up on the seabed. Their shells and skeletons broke into small pieces. Over millions of years, the sediments stuck together to form limestone. The process is still happening in the sea around the islands of the Bahamas.

Limestone often contains fossils.

Cement is made from limestone.

Making sedimentary rocks – an introduction

It takes millions of year to make sedimentary rocks. The process happens in stages. The diagram below summarises these stages.

$\underbrace{\text{weathering} \rightarrow \text{transportation}}_{\text{erosion}} \rightarrow \text{deposition} \rightarrow \text{compaction or cementation}$

Q

1. Name three sedimentary rocks.
2. Explain why claystone is used to make bricks, and why sandstone is used to make buildings.
3. Sundara has a rock. Suggest how she could find out if the rock is a sedimentary one.
4. Describe two properties of sedimentary rocks. Explain why sedimentary rocks have one of these properties.

!

- Use a hand lens and water to identify sedimentary rocks.
- Sandstone, claystone, mudstone, and limestone are sedimentary rocks.
- Rock uses are linked to their properties.

4.4 Sedimentary rock formation

Objectives

- Explain how rocks are weathered
- Explain how sediments form rocks

Weathering

Weathering breaks up all types of rock into smaller pieces, called **sediments**. Sediments can be huge boulders or tiny pieces of clay. The sediments may end up in new sedimentary rocks, or they may end up as part of the soil.

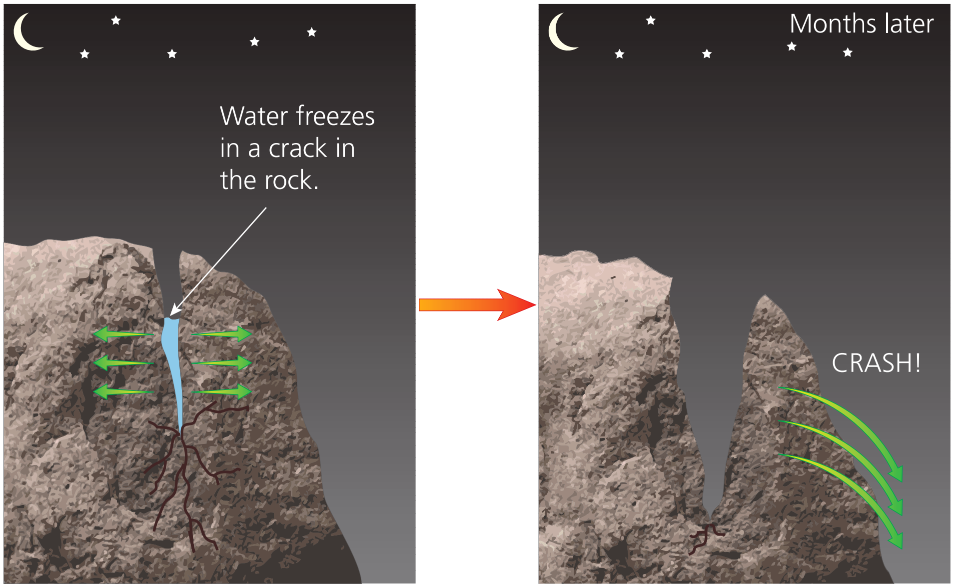
There are three types of weathering: physical, chemical, and biological.

Physical weathering

Physical weathering is caused by the effects of changing temperature on rocks. It makes rocks break apart.

One type of physical weathering is freeze-thaw weathering. It happens when water gets into rock cracks:

- On cold nights, water freezes to form ice.
- As the water freezes, it expands.
- The ice pushes against the sides of the crack. The crack gets bigger.
- This happens again and again. The rock breaks.



Freeze-thaw weathering.

Chemical weathering

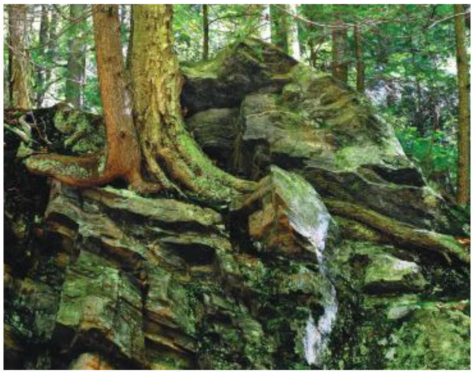
When rainwater falls on some rocks minerals, new substances are formed. This is **chemical weathering**. Chemical weathering happens more in acidic rain.

This limestone carving was made about 1000 years ago at El Tajin, Mexico. Acid rain is breaking up its surface by chemical weathering.

Biological weathering

Plants and animals break up rocks in many ways. For example:

- Tree roots grow through rock cracks to find water. As the tree grows, its roots gradually break the rock.
- Lichens make chemicals which break down rocks so that the lichens can get the nutrients they need.



Tree roots break up rocks as they grow.

Transportation

Weathering breaks up rock into smaller sediments. These sediments are moved away from their original rock by **transportation**.

Transportation can happen by gravity, or by wind, water, or ice.

Water carries pebbles along the river bed.

The wind carries sand grains from place to place.

Gravity moves sediments in rock falls and landslides.

The processes of weathering and transportation together make up **erosion**. Erosion is different from weathering:

- Weathering is the breakdown of rock into sediments.
- In erosion, a rock is broken into sediments, *and* the sediments are moved away.

New rocks are formed!

Eventually sediments stop moving away from their original rock. They settle in layers. This is **deposition**.

Then the sediments form new rocks. This happens by one of two processes:

- In **compaction** the weight of the layers above squash the sediments together tightly. The sediments are the grains of the new rock.
- In **cementation** new minerals stick the sediments together.

Sediments were laid down in layers to form this sedimentary rock.

Q

1. Describe two ways that a grain of rock could be transported from one place to another.
2. Explain what is meant by *weathering*.
3. **Extension:** Describe three ways in which weathering occurs.

!

- Weathering breaks up all types of rock to make sediments.
- Sediments can be transported by gravity, wind, water, or ice.
- New rocks are formed when sediments settle and are squashed together, or stuck together by new minerals.

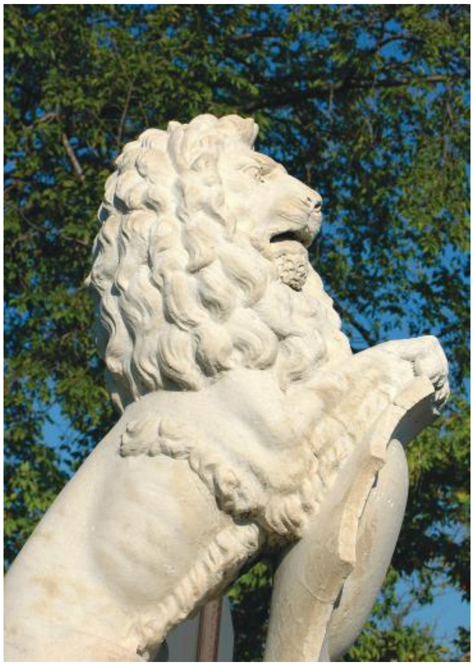
4.5 Metamorphic rocks

Objectives

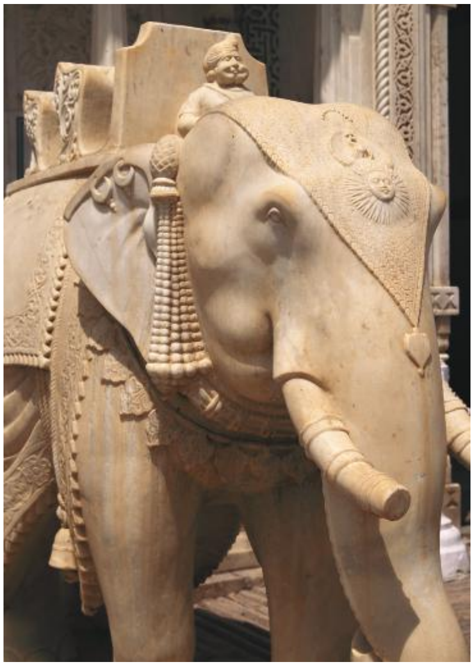
- Explain how metamorphic rocks are made
- Identify metamorphic rocks
- Give examples of metamorphic rocks

The same but different

Skilled craftspeople carved these beautiful sculptures from natural rock. The rocks of the two sculptures look and feel very different.



This sculpture is made from limestone.



This sculpture is made from marble.

Both types of rock are mainly one mineral – calcite. The table shows the properties of the two rocks.

Rock	Colour	Texture
Limestone	White, grey, or cream.	Surface often rough. Tiny rounded grains. Gaps between the grains. Fossils often visible.
Marble	Usually white. Often has whirling streaks or spots of brown, red, blue, or yellow.	Surface usually smooth. Interlocking, evenly sized crystals. No gaps. No fossils.

Marble from limestone

Hot magma makes surrounding rocks change.

Conditions are hostile beneath your feet. Just 15 km below the Earth's surface the temperature is 400 °C. The pressure at that depth is 4000 times greater than the surface pressure.

In some places, hot magma comes close to the surface. It heats up the rocks around it. The heat makes rocks change.

When limestone gets hot, its atoms arrange themselves in a new pattern. This makes big crystals which interlock tightly. A new rock has been made – its name is marble.

Both marble and limestone consist mainly of one mineral – calcite. White marble is pure calcite. Coloured marble has tiny amounts of other minerals mixed with the calcite.

Metamorphic rocks

Marble is a **metamorphic rock**. Metamorphic rocks form when heat, or high pressure, or both, change igneous or sedimentary rocks. The rocks remain solid during the process. They do not get hot enough to melt. The changes happen in the Earth's crust.

All igneous and sedimentary rocks can be changed into metamorphic rocks. So there are many different metamorphic rocks.

Recognising metamorphic rocks

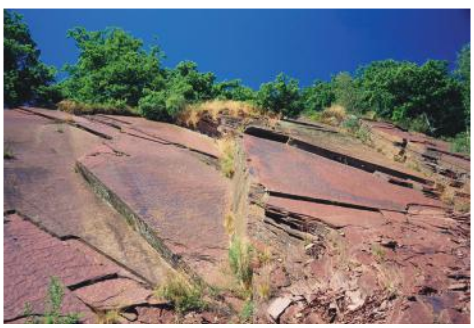
Metamorphic rocks are made up of crystals. This means that:

- metamorphic rocks are not porous
- you cannot see separate grains when you look at the rock through a hand lens.

Metamorphic rocks often look squashed or stripy. Some types are made up of thin layers.

More examples of metamorphic rocks

Slate splits into smooth flat sheets. This means it makes good roofing tiles.



Slate is made up of layers.

This fossil formed in mudstone. Its shape changed when high pressures converted the mudstone into slate.

Slate was formed from mudstone. Mudstone is a sedimentary rock. It is a mixture of minerals. High pressures underground squash mudstone. Water is squeezed out. New crystals form and arrange themselves in layers. If the mudstone contains fossils, so will the slate, but they will be squashed out of shape.

Gneiss is another metamorphic rock. It is hard, and often stripy. It is made up of big, interlocking crystals. It was formed at high temperatures and pressures deep within the Earth's crust.

A piece of gneiss.

Q

1. Name three metamorphic rocks.
2. Explain how metamorphic rocks are formed.
3. Explain why metamorphic rocks are not porous.
4. Raj has a piece of rock. Suggest how he could find out whether it is sedimentary or metamorphic.

!

- Metamorphic rocks form when rocks are changed by high temperatures or pressures.
- Metamorphic rocks have interlocking crystals.
- Marble, slate, and gneiss are metamorphic rocks.

Enquiry

4.6

Questions, evidence, and explanations: the rock cycle

Objectives

- To understand why questions, evidence, and explanations are important in science
- To interpret the rock cycle

Asking questions

This picture shows some **geologists** at work. Geologists don't just collect rocks. They ask questions about the Earth. How was the Earth formed? What is it made from? How and why does it change?

Early evidence and explanations

For many years, people have wondered about this question:

What makes mountains?

Scientists worked hard to answer this question. They made careful observations. They thought about their evidence, and used it to create explanations. For example:

One thousand years ago Ibn Sina of Kazakhstan observed layers of rock in mountains.

He described his evidence:

We see that mountains appear to be piled up layer by layer.

Ibn Sina considered the evidence.

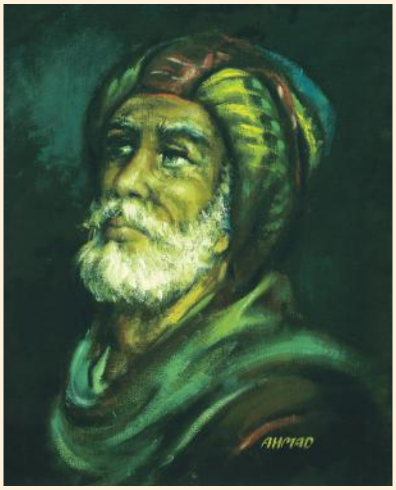
He wrote an explanation:

It is therefore likely that the clay from which mountains were formed was itself at one time arranged in layers. One layer was formed first and then at a different period a further layer was formed and piled upon the first, and so on.

Eight hundred years ago Chinese thinker Chu Hsi found fossilised seashells on a mountain top. He considered this evidence, and realised that the shellfish once lived in the sea.

He created an explanation:

Everything at the bottom came to be at the top.



Ibn Sina

Piecing together the evidence

Geologists continued to collect evidence about mountain making, and about how rocks are made. In the 1700s James Hutton thought about the evidence. Could he create an explanation to link it all together?

Eventually James Hutton came up with an explanation. He called it the **rock cycle**. The rock cycle explains how rocks change and are recycled into new rocks over millions of years. It also answers our original question:

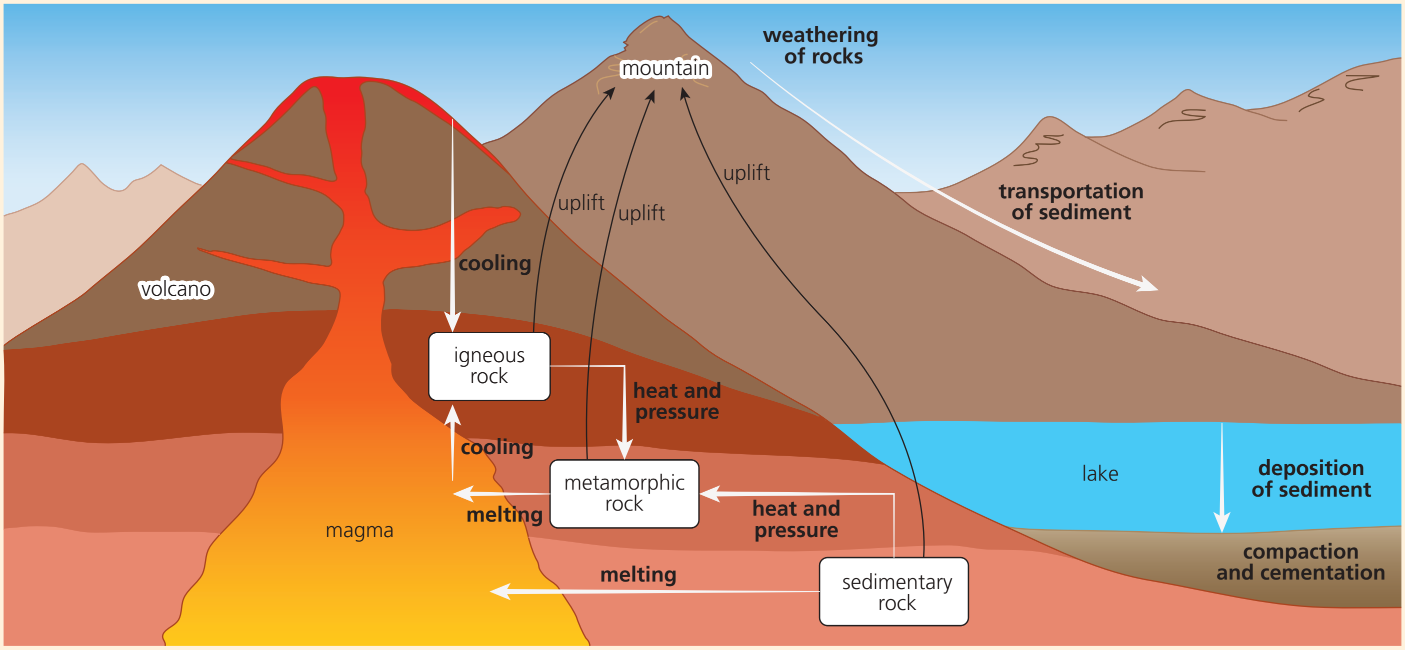
What makes mountains?

The rock cycle

Erosion wears down mountains. The sediments make sedimentary rocks. Under the Earth's surface, high temperatures and pressures may turn sedimentary or igneous rocks into metamorphic rocks.

Some rocks sink deep under the surface. They get hot enough to melt and make magma. The magma is pushed upwards. Some of the magma cools and solidifies underground. Some magma comes out of volcanoes, and solidifies on the surface. Igneous rocks are made.

At any time, huge forces from inside the Earth may push rocks upwards to make mountains. This is called **uplift**. This means that any type of rock – sedimentary, igneous, or metamorphic – may end up on a mountain top.



The rock cycle.

1. Outline how a scientist may develop an explanation.
2. Use the rock cycle to outline how mountains are made.
3. Use the rock cycle to describe one way in which matter is recycled in rocks.

- To develop explanations, scientists ask questions, suggest ideas, and collect evidence.
- The rock cycle shows how matter is constantly recycled in rocks.

Enquiry
4.7

Using science to explain predictions: volcanoes

Objective

- Understand how scientists use science to explain predictions

Eruption!

Pertiwi lives in Java, Indonesia. She writes a diary.

23 October 2010

There were more earthquakes today.
They say it's the volcano getting ready to erupt.
It's scary!

Mount Merapi, Indonesia, erupted in October 2010.

25 October 2010

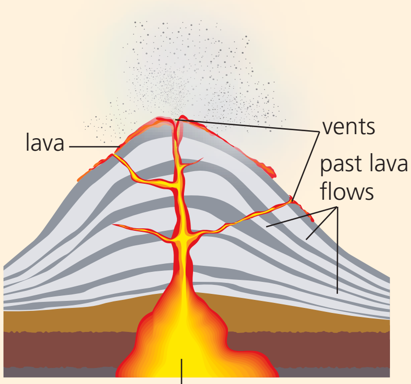
My grandparents have been evacuated - now they are staying with us. The volcano has erupted and there is lava spewing down the southern slopes.

26 October 2010

The volcano refuses to rest. Showers of red-hot rock have been flung high into the sky. There are flames, smoke and poisonous gases, which are hotter than boiling water, erupting from the volcano. The gases can move faster than cars. There have been several deaths – it's a tragedy!

30 October 2010

The volcano is still active. There's black soot everywhere and sand is raining down. There was a massive fire ball. Thousands of people are travelling to safety, including us...



Inside a volcano.

What comes out of volcanoes?

The rock underneath a volcano is very hot. It melts to make **magma**. Magma collects under and inside volcanoes. It comes out of a volcano as liquid **lava**. Volcanoes also fling out solid materials (like volcanic 'bombs' and ash) and gases (including sulfur dioxide, carbon dioxide, and water vapour).

Explaining predictions

It's impossible to know exactly when – or how – a volcano will erupt. But vulcanologists work hard to predict what a volcano will do next. They tell people when to evacuate their homes and get out of the way.

Vulcanologists make observations and measurements. They look for patterns in their data. They use these patterns to help them make predictions. Vulcanologists support their predictions with scientific explanations.

My tilt meter measures the steepness of the volcano slope. I predict that, when the steepness changes, the volcano is more likely to erupt.

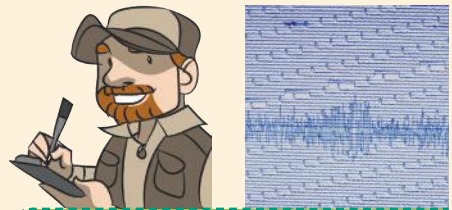
Explanation:

Changes in the shape of a volcano show that magma is moving inside the volcano. Moving magma means an eruption is likely.

I measure the amount of sulfur dioxide gas coming out of the volcano. I predict that, if the amount of sulfur dioxide increases suddenly, the volcano will erupt.

Explanation:

Magma contains dissolved sulfur dioxide gas. The gas escapes when magma rises to the surface. Extra sulfur dioxide shows that magma is near the surface. An eruption is likely.



I monitor earth movements near the volcano. I predict that, if earth movements increase, the volcano will soon erupt.

Explanation:

Earth movements may be caused by magma pushing up against the surface rock. If magma is moving, an eruption is likely.

Benefits of volcanoes

Since 1500, volcanoes have killed around 200 000 people. But volcanoes are not all bad. Soils formed from volcanic rock are very fertile, so plants grow well. Water pumped underground gets very hot in volcanic areas. Steam from hot underground rocks generates electricity in many countries, including Indonesia and the Philippines.

Q

1. State why vulcanologists make predictions about when a volcano will erupt.
2. Explain why scientists monitor earth movements around volcanoes.
3. Explain why extra gas coming out of a volcano is evidence that a volcano might soon erupt.

!

- Vulcanologists use science to explain volcano predictions.

4.8 Soil

Objectives
- List soil components
- Name soil types
- Describe soil properties

Vital soil

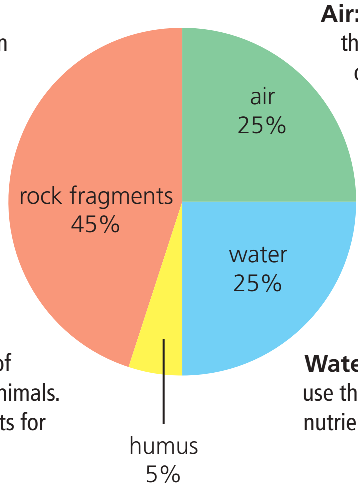
Soil is vital. It holds plant roots in place, and provides plants with essential nutrients. Without soil, there would be few plants. Without plants, there would be few animals.

What is soil?

Soil is a mixture. The pie chart shows its main components. Read on to find out more about these components.

Rock fragments are small pieces of rock. They come from rocks that have been broken up by weathering.

Air: all plant organs respire, including their roots. They need a good supply of oxygen. When water is removed from soil, air replaces it.



Humus is made up of decayed plants and animals. It is a store of nutrients for microbes.

Water is a vital part of soil. Plants use their roots to absorb water. Soil nutrients dissolve in water, so plant roots can take them in.

The components of a typical soil.

Soil is also home to lots of living things, like earthworms, insects, and other small animals. These help with decay processes and change soil structure.

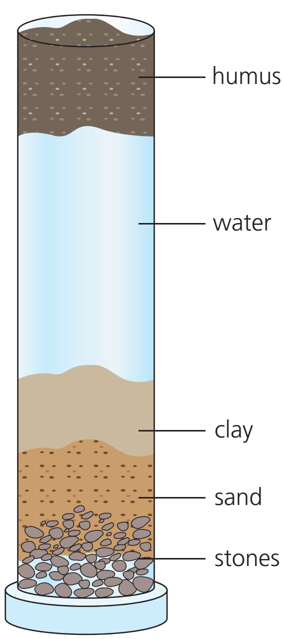
Soil types

Rock fragments in soil have different sizes. Their sizes help determine the properties of a soil, and how well plants grow in it.

Scientists have classified the size of rock fragments.

Name of rock fragment	Fragment diameter (mm)
small stones	more than 2.00
sand	0.05 – 2.00
silt	0.002 – 0.05
clay	less than 0.002

You can separate the different types of rock fragment by adding water to soil in a measuring cylinder. Shake, and leave to settle.



You can separate soil components by adding water to soil and shaking.

The main types of soil are:

- **Clay soil** – At least 40% of the rock fragments are clay.
- **Sandy soil** – Most of the rock fragments are sand.
- **Loam** – The rock fragments in this soil are 40% sand, 40% silt, and 20% clay.

Soil properties

The properties of a soil determine how well things grow in it. You can compare several important soil properties in the laboratory – or outside.

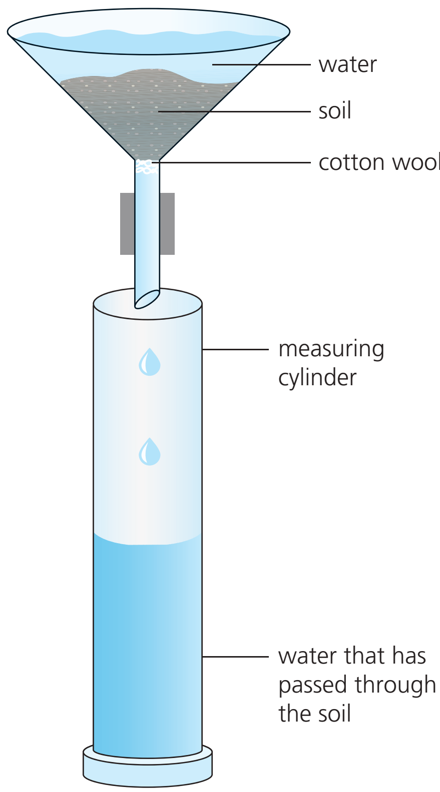
Soil texture

To find out about the texture of a soil, rub it between your thumb and fingers.

- Sandy soil feels gritty.
- Dry silty soils feel floury.
- Clay soils feel sticky when wet and hard when dry.

Soil drainage

Water drains quickly through some soils, and slowly through others. You can use the apparatus on the right to test soil drainage.



Apparatus to test soil drainage.

Salama takes three soil samples of the same mass. She pours 100 cm^3 water onto each sample. She measures the volume of water in the measuring cylinder after 30 minutes. Her results are in the table.

Type of soil	Volume of water collected in 30 minutes (cm^3)
clay	19
sand	91
loam	52

The results show that water drains most quickly through sandy soil. This means that, in sandy soil, water is available to plant roots for just a short time. Soluble nutrients leave the soil quickly.

Turn over to read more about testing soil properties.

Q

1. Name the four main components of soil.
2. Describe how to separate soil components.
3. Describe and explain three differences between a sandy soil and a clay soil.
4. Predict which will drain more quickly – sandy soil or clay soil. Explain why.

!

- Soil is made up of rock fragments, humus, living things, air, and water.
- The main types of soil are clay, loam, and sand.
- You can test soils for texture and drainage.

Enquiry

4.9

More about soil

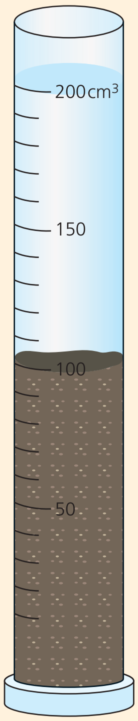
Objectives

- Describe soil properties
- Explain why soil properties are important

Soil water content

Different types of soil can hold different amounts of water in their **pores** (spaces between the solid matter). Sandy soil holds very little water. Clay soils hold more water. The table shows the percentage of soil that is water for three different soil samples.

Type of soil	Percentage of soil that is water when the smallest pores are filled with water and the biggest pores are filled with air and water
sand	7
loam	18
clay	23



Measuring the volume of air in a soil sample.

Soil air content

The amount of air in a sample of soil depends on how wet the soil is. Soil pores can be filled with air or water. The more water in a soil, the less space there is for air.

Pavan and Badal take soil samples to school. They want to compare the amounts of air in the two soils. This is what they do:

- Place 100 cm^3 soil in a measuring cylinder.
- Add water to the 200 cm^3 mark.
- Stir until there are no more air bubbles leaving the soil.
- Read the new water level on the measuring cylinder.
- Calculate the volume of air in the soil. This is:
  the original water level (200 cm^3) – new water level after stirring.

The students' results are in the table below.

Soil sample	First reading of water level (cm^3)	Final water level reading (cm^3)	Volume of air in soil sample (cm^3)
Pavan	200	190	10
Badal	200	170	30

Soil pH

Cassava grows in soils of pH 4 to 8.

Ayu and Dian are at the same school. Ayu's family grow cassava and sweet potatoes on their farm. They tried growing peanuts, but the crop was poor. Dian's family grow peanuts and soya beans.

Ayu and Dian ask a question:

Why do different crops grow well on the two farms?

The students wonder if soil pH is the reason. They collect evidence to test their idea.

Ayu and Dian each take a sample of soil. They shake it up with Universal Indicator in a test tube. They record their soil pH values.

Farm	Soil pH
Ayu	7.5
Dian	6.0

Ayu and Dian also collect evidence from secondary sources on the Internet. They find out the preferred soil pH for four crops.

Crop	Preferred soil pH
Cassava	4.5 to 7.5 (tolerates 4 to 8)
Sweet potatoes	5.5 to 6.5 (tolerates 4.5 to 7.5)
Peanuts	best is 6.0
Soya beans	best is 6.0

Ayu and Dian write an explanation to answer their question:

Soil pH explains why different crops grow well on our farms. Dian's crops grow well on soil of pH 6.0. Ayu's crops grow in soil of higher pH.

If Ayu's family want to grow peanuts or soya beans they will need to lower their soil pH by adding acid.

Soil colour

Soil colour provides evidence for the minerals in soil. Red soils may be rich in iron minerals. Humus-rich soils are black or dark brown.

Red soils are rich in iron minerals.

Q

1. Name the element present in red soil minerals.
2. Describe how to measure the amount of air in a soil sample.
3. A third student measured soil air content, like Pavan and Badal. The first water level reading was 200 cm^3. The final water level reading was 180 cm^3. Calculate the volume of air in the soil.

!

- You can measure soil air content, and pH.
- Different crops grow best in soils of different pH.

4.10 Fossils

Objectives
- State what a fossil is
- Describe how fossils form
- Give examples showing what we can learn from the fossil record

Learning from fossils

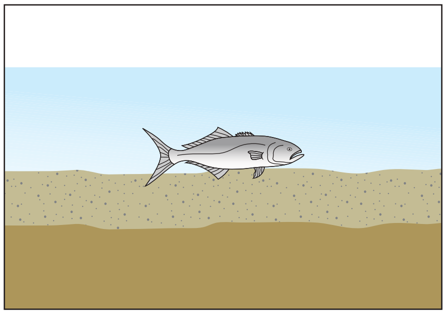
The pictures show three **fossils**. What can fossils tell us about our human past? The history of life on Earth? The origin of the Earth itself? Read on to find out.

What are fossils, and how are they made?

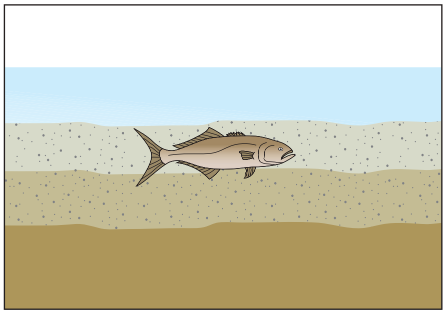
Fossils are the remains or traces of a plant or animal that lived many years ago. They have been preserved by natural processes. Usually only the hard parts of living things are fossilised.

Fossils form very rarely. Normally a dead animal is eaten, or it rots away. But occasionally one is buried quickly by sand or mud – perhaps on a river bed or under the sea. Here the dead body is safe from animals that might eat it.

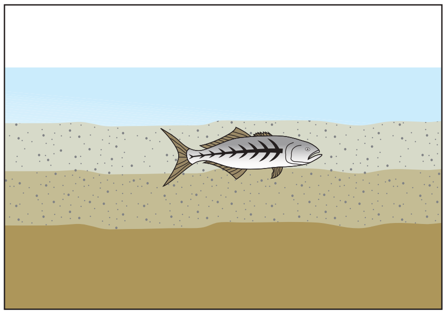
A fossil may then form. This can happen in several ways. The pictures below show one method of fossil formation.



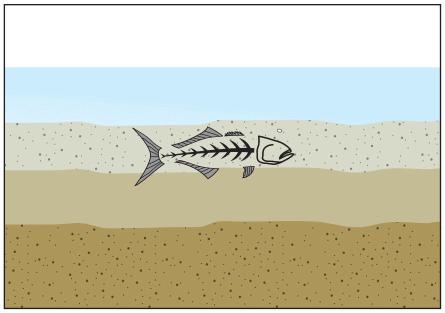
An animal dies. It falls onto mud or sand.



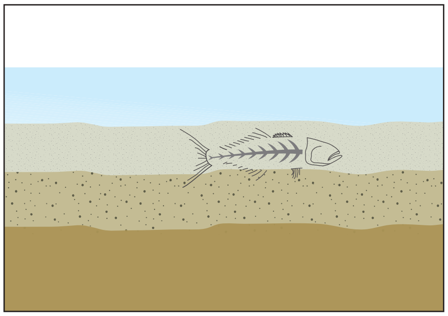
More mud or sand quickly buries the body.



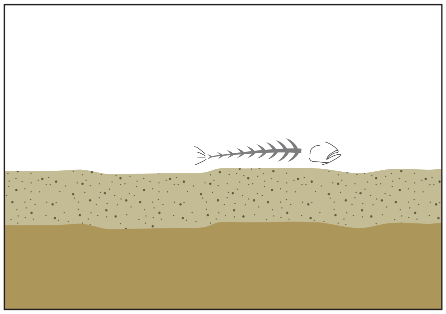
Bacteria slowly break down the soft parts of the body. Its skeleton remains.



The mud or sand above and around the skeleton starts to become rock.



As rock forms, underground water that is rich in dissolved minerals seeps into tiny spaces in the skeleton. These minerals gradually replace the original minerals of the skeleton. A hard copy of the original skeleton is formed.



Many years later, soft rock around the fossil is eroded. The fossil is exposed.

What do fossils tell us about the history of life on Earth?

Palaeontologists collect and study fossils. They use evidence from fossils to help piece together the history of life on Earth. Fossils tell us about the features of animals and plants that lived at different times, and about their changing environments. All the evidence from fossils, taken together, is the **fossil record**.

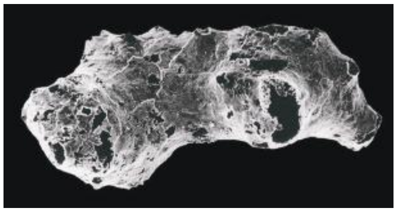
Oldest plants

In 2010 Claudia Rubinstein and her team found fossils from the earliest known land plants in Argentina. The plants lived more than 470 million years ago. The plants were a type of liverwort, which have no roots or stems. This new find suggests that all land plants may have evolved from liverworts.

A modern liverwort.

Oldest animals

In 2012 a team of palaeontologists discovered sponge-like fossils in Namibia. The fossils are the oldest record of animal life ever found. Scientists previously thought that animal life began between 600 and 650 million years ago. These fossils could be up to 760 million years old.



Fossils of *Otavia antiqua* are the earliest record of animal life ever found.

Dinosaurs

Without fossils, we would not know about dinosaurs.

This dinosaur embryo, found in South Africa, is about 190 million years old. It was close to hatching when it was buried.

Fossilised dinosaur faeces tell us what dinosaurs ate, and about the environments they lived in.

Q

1. Explain why only very few plants and animals form fossils.
2. Describe the stages by which a fossil forms.
3. Choose an example of a fossil find, and describe what scientists have learnt as a result of it.

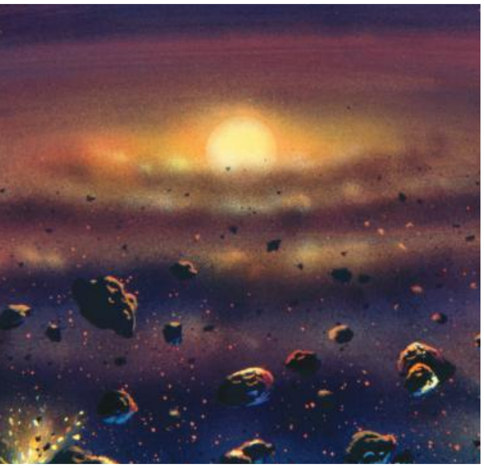
!

- Conditions must be perfect for fossils to form.
- The fossil record tells us about the history of life on Earth.

4.11 Estimating the age of the Earth

Objective

- Describe how scientists have estimated the age of the Earth



Our Solar System formed from clouds of dust and gas.

Older strata are found beneath younger ones.

The story of our Earth

Many years ago, a great swirl of dust and gas came together in space. It formed our Solar System. Most of the dust and gas ended up in the Sun, but some was left over. Gravity pulled this dust and gas into clumps. The clumps became planets. Our Earth was born.

When did this happen? How old is the Earth? Read on to find out.

Cooling calculations

Scientist William Thomson examined evidence showing that the temperature of the Earth's crust increases with depth. He assumed the Earth formed as a liquid.

Thomson calculated the time needed for the Earth to cool to its current surface temperature. He worked out that the Earth formed between 20 and 400 million years ago.

We now know that Thomson did not realise that heat is produced inside the Earth. His assumption – that the Earth formed as a liquid – is also wrong. The Earth is older than Thomson thought.

Relative dating from rock strata

Sedimentary rocks are built up layer by layer, over millions of years. The layers are called **strata**. Where rock is undisturbed, the oldest rock layer is on the bottom. Younger layers are deposited above.

Fossils and strata

William Smith worked in coal mines. Around 1800, he noticed that different rock strata contained different fossils. He realised that, in his coal mine, a certain rock layer always contained the same fossils. Smith asked a question:

Would rock strata of the same age always contain fossils of the same living organisms, even in different places?

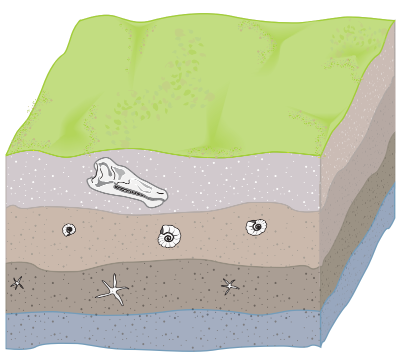
Smith travelled to collect evidence to help answer his question. He published his findings so that other scientists could also look for evidence.

He used the evidence to devise an explanation:

Rock strata of the same age contain fossils of the same living organisms.

Certain fossils are only found in rock strata of certain ages.

Evidence from fossils in strata is useful in working out the order of events.



A fossil in a lower rock layer is probably older than one in a layer above it.

Geological time scale

Scientists used Smith's explanation to classify rock strata by the fossils they contained. By the 1850s they had divided the Earth's history into geological time periods. At the time, they did not know when the rocks in each time period were formed.

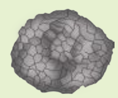
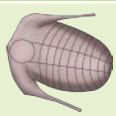
The names of the geological time periods are shown in the table on the right. Each time period has its own **index fossil** to help identify it.

Radioactive dating

Evidence from strata and index fossils is useful in working out the order of events. But simply looking at strata cannot tell us how old they are.

In the twentieth century scientists used a new technique to measure the ages of rocks – **radiometric dating**. This uses the natural decay of the particles in a rock to measure its age. Radiometric dating tells us when rocks in different geological time periods were formed.

The oldest rocks on Earth are 4 600 000 000 years old. This is the best estimate for the age of the Earth.

Geological time period	Index fossil	Approximate date for start of time period (million years ago)
Quaternary		2.6
Tertiary		66
Cretaceous		146
Jurassic		200
Triassic		251
Permian		299
Carboniferous		359
Devonian		416
Silurian		444
Ordovician		488
Cambrian		542

Geological time periods and their index fossils.

Q

1 Give the best estimate for the age of the Earth.
2 William Thomson estimated the age of the Earth. Explain why his answer was incorrect.
3 Explain how index fossils are useful.

!

- Rock strata tell us about the order of events.
- Index fossils identify geological time periods.
- Radiometric dating measures the ages of rocks.

Extension
4.12

Human fossils

Objective

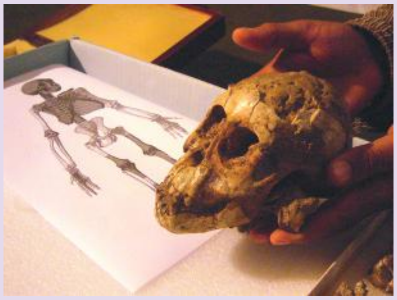
- Describe what fossils tell us about our human past

Selam

It's the end of a hot day in Dikika, Ethiopia. Scientist Zeresenay Alemseged and his team have spent weeks looking for human fossils. They've found fossilised bones of otters and elephants. Could humans have lived here too?

Zeresenay at work.

Suddenly, someone spots a small fossil face. It has a smooth brow and short canine teeth. The face looks human.



Zeresenay pieced together Selam's skull.

For five years Zeresenay studies the evidence. He works out that the skull, and other nearby bones, probably belonged to a three-year-old girl. He names her Selam. She almost certainly walked upright, like modern humans.

Geologists examine the rocks around Selam. The evidence shows that she lived by a river. Fossilised snails in nearby sandstone show that the river flowed into a lake with sandy beaches.

Many of Selam's fossilised bones were in a big lump of rock made from sand and pebbles. This shows that Selam probably died in a river flood. Fast-flowing water carried pebbles and sand that quickly covered her body and stopped animals from eating it.

Radiometric dating of the surrounding rock shows that Selam died about 3 300 000 years ago.

More fossil finds

Selam's fossilised bones, and their surrounding rocks, tell us when she lived and what her environment was like. Scientists have found many other human fossils. These finds help to piece together our human past.

Toumaï – ape or human?

In 2001 scientists discovered fossilised skull bones in Chad. They named their find Toumaï. The fossils were found in 7 million-year-old sand. If the fossils are the same age as the sand, they are older than any human remains in the fossil record.

Scientists examined Toumaï. They compared the skull bones to those of modern chimpanzees and humans. They decided that Toumaï belonged to an extinct species.

Animal	Number of teeth	Canine teeth	Average skull volume (cm^3)
Toumaï	32	small	325
chimpanzee	32	big	390
gorilla	32	big	350
modern human	32	small	1500

Skulls of Toumaï, a gorilla, a chimpanzee, and a modern human.

Scientists disagree about whether the extinct species is an ancestor of modern humans. Some believe the evidence shows that it is an ancestor of both chimpanzees and humans. Other scientists think that Toumaï is more closely related to the modern gorilla. The debate continues.

Footprints in Laetoli

More than three million years ago, early humans made these footprints in what is now Tanzania. Soon after, they were covered in volcanic ash. Scientists discovered the ancient footprints in 1978.

Scientists have compared the footprints to those of modern humans. They provide some of the earliest evidence of humans walking on two legs. They were probably made by an early species of humans called *Australopithecus afarensis*.

Footprints at Laetoli.

Tiny humans

Scientists discovered the remains and tools of an extinct human-like animal in a cave on the island of Flores, Indonesia. They measured the bones, and worked out that the animal was just one metre tall.

The scientists believe they had discovered an extinct human species. They named it *Homo floresiensis*. Other scientists think that the remains are from modern humans.

The *Homo floresiensis* fossils were found in this cave in Indonesia.

Q

1. Explain how scientists worked out that Selam lived near a lake with sandy beaches.
2. Explain how scientists know when Selam died.
3. Explain why scientists are not sure which species Toumaï belongs to.

!

- Fossils tell us about our human past.

Review 4.13

1 Complete these sentences using words from the list. You may use each word once, more than once, or not at all.

igneous **metamorphic** **sedimentary**

Scientists classify rocks in three groups. Rocks that were formed when magma cooled and solidified are _______ rocks. Rocks formed from fragments of rock are _______ rocks. Rocks formed by the action of heat and pressure on existing rock are _______ rocks. [3]

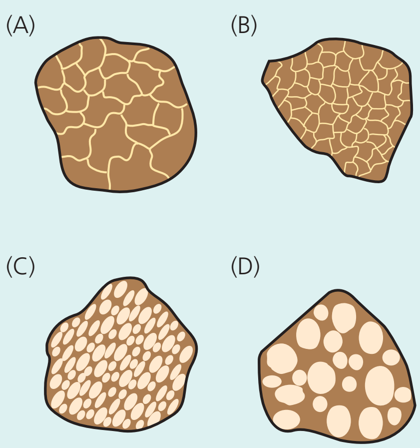
2 Copy and complete the table using the words below.

sandstone **granite** **marble**

Type of rock	Example
igneous	
sedimentary	
metamorphic	

[3]

3 This question is about the four types of rock shown in the diagrams below.



a Give the letters of two igneous rocks. [1]

b Give the letter of the igneous rock that cooled more slowly. [1]

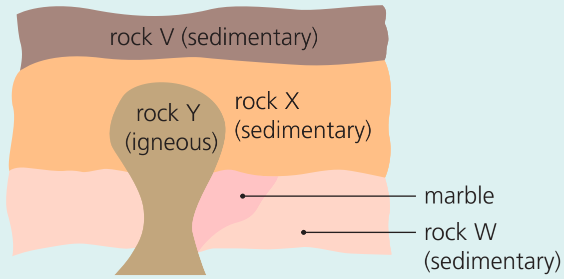
c Give the letters of two porous rocks. [1]

d Give the letters of two rocks that formed when magma cooled and solidified. [1]

e Give the letter of two rocks which could contain fossils. [1]

f Give the letters of two rocks that are made up of crystals. [1]

4 The diagram shows the rocks in the wall of a mine.



a Which rock could contain fossils (V, W, X, or Y)? [1]

b Which is the youngest sedimentary rock? [1]

c Which is most likely to be limestone? Explain your choice. [2]

d Suggest how the marble formed. [1]

e Which is most likely to be granite? Explain your choice. [2]

5 The photograph shows a piece of pumice.

A student investigated the properties of pumice. He also found out about pumice from secondary sources. He wrote down the notes below.

1 *I put it on water and it floated, so it must have a low density.*

2 *When I pushed the pumice into a beaker of water, bubbles rose to the surface.*

3 *My text book says pumice is formed from hot lava when it is thrown high into the air by a volcano. The gases that were dissolved in the lava come out of solution, forming the 'bubbles' you can see.*

a Give the number of the note which shows that pumice is an igneous rock. [1]

b Use evidence from the notes to describe two ways in which the properties of pumice are not typical of igneous rocks. [2]

c Which note(s) refer to a secondary source? [1]

d **i** Copy the part of the sentence in note 1 which is an observation. [1]

ii Copy the part of the sentence in note 1 which is an explanation. [1]

6 Two students investigate some rocks. They write their results in the table below.

Rock	Is it made up of crystals or grains?	Is it porous?	Does the piece of rock contain fossils?
A	grains	yes	no fossils
B	crystals	no	yes, but its shape looks squashed
C	crystals	no	no

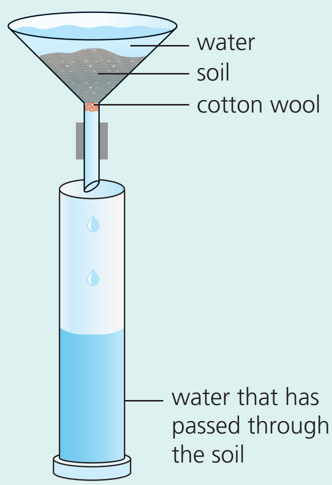
a Name a piece of equipment the student could use to help her decide whether a rock is made up of crystals or grains. [1]

b Which rock is probably a metamorphic rock? [1]

c Which rock might be basalt? [1]

d One of the students, Junaid, says that rock A is a sedimentary rock. The other student, Farooq, says that rock A cannot be a sedimentary rock because it contains no fossils.
Write the name of the student you think is correct. Give a reason for your decision. [2]

7 A student compares the drainage of three soil samples. She uses the apparatus below.



The student writes her results in a table.

Soil sample	Volume of water collected in 1 hour (cm^3)
L	15
M	89
N	48

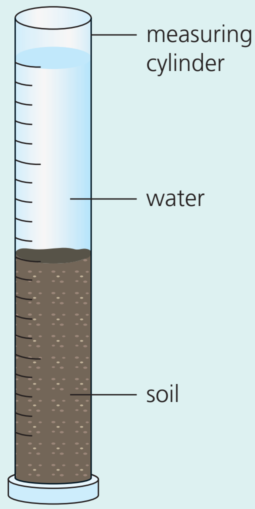
a Give the letter of the soil which drains water most quickly. [1]

b Give the letter of the soil from which nutrients are removed most quickly. [1]

c Give the letter of the soil which remains wet for the longest time after heavy rain. [1]

d Give the letter of the soil which is most likely to be a clay soil. [1]

8 A student wants to compare the amounts of air in soil samples from two fields. She uses the apparatus below.



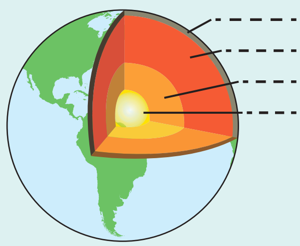
She observes the level of water in the measuring cylinder after shaking the mixture of soil and water. The lower the water level, the greater the volume of air that was in the soil.

a Name the variable that the student changes. [1]

b Name the variable that the student observes. [1]

c Suggest two variables that the student should keep constant. [2]

9 The diagram shows the structure of the Earth.



a Use the words below to label a copy of the diagram.

outer core **crust**
mantle **inner core**

b Copy and complete the table below.

Layer	Solid, liquid, or gas?
crust	
inner core	
mantle	
outer core	

10 The statements below explain how a fossil was formed. They are in the wrong order. Write the letters in the correct order. [4]

a The soft parts of the body slowly break down. Only the bones are left.

b More sand quickly buries the body.

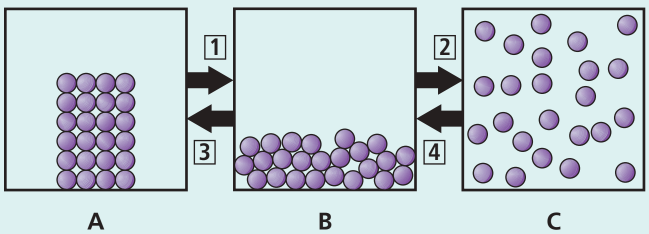
c An animal dies. It falls onto sand at the bottom of a lake.

d Underground water that is rich in minerals seeps into the gaps in the bones. The minerals replace the original minerals of the skeleton.

e The sand above the bones is compressed, and begins to form rock.

Review Stage 7

1 Bromine can exist as a solid, liquid, or gas. The diagrams show the arrangements of particles in each of these states.



a Give the name of the state represented by diagram A. [1]

b Give the name of the change of state that is represented by arrow 1. [1]

c Describe how the movement of the particles changes during the change of state represented by arrow 3. [1]

d A student collects data about bromine.

melting point of bromine = –7 °C
boiling point of bromine = 59 °C

i Give the letter of the diagram that best represents the particles in bromine at 20 °C. [1]

ii Give the letter of the diagram that best represents the particles in bromine at –10 °C. [1]

iii At what temperature does the change represented by arrow 3 occur? [1]

2 A student investigated the variables that affect the time taken for 20 g of sugar to dissolve in water.

a The student changed one variable in the first part of her investigation. Her results are in the table.

Investigation 1

Temperature (°C)	Time to dissolve (s)
0	400
20	100
40	25
60	12
80	3

i Name the variable the student changed in Investigation 1. [1]

ii Plot the points in the table on a graph. Draw a line of best fit. [4]

iii Write a conclusion for Investigation 1. [1]

b The student changed a different variable in the second part of her investigation. Her results are in the table.

Investigation 2

Size of pieces of sugar	Time to dissolve (s)
big crystals	100
small crystals	70
very fine powder	50

i List three variables the student should have kept constant in Investigation 2. [3]

ii Write a conclusion for Investigation 2. [1]

c The student did Investigation 2 at 20 °C. Use the data in both tables to suggest what size sugar pieces she used in Investigation 1. [1]

3 From the list below, write the properties that are typical of metals.

high melting point	**shiny**
dull appearance	**malleable**
poor conductor of heat	**sonorous**
low boiling point	**brittle**
good conductor of electricity	

[5]

4 This question is about the pH of the water in three East African lakes.

The pH range of the water in each lake is given in the table below.

Name of lake	pH range of lake water
Lake Malawi	7.8–8.6
Lake Tanganyika	7.2–8.6
Lake Victoria	8.6–9.5

a In which lake can the most alkaline water be found? [1]

b A student collected a sample of water from Lake Victoria. She added a few drops of Universal Indicator to the water. Use data from the table, and the diagram below, to predict the colour of this mixture. [1]

	acidic			neutral	alkaline		
colour of indicator	red	orange	yellow	green	blue	dark blue	purple

c Read the paragraph in the box. It is from a book about Lake Malawi.

> The pH of Lake Malawi water is different in different parts of the lake. In calm bays, more carbon dioxide dissolves in the water. Carbon dioxide gas is acidic, so the water in calm bays is more acidic.
>
> Where the water is not calm, the water is more alkaline. This is because less carbon dioxide is dissolved in the water.

Use the information in the box, and data from the table, to predict the pH in a calm bay of Lake Malawi. [2]

d Predict how the pH of the lakes might change if the rain in the region became more acidic. [1]

e The picture shows one species of tilapia fish. [1]

Tilapia prefer to live in water of pH 6 to 9. However, many can survive in water of pH 5 to 10. Predict which of the lakes in the table are suitable for tilapia.

5 This question is about igneous rocks.

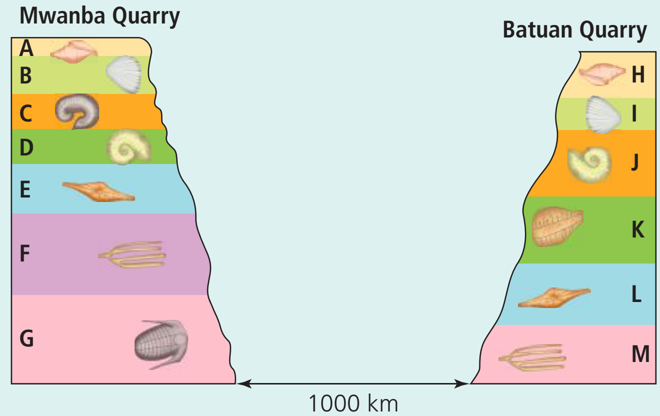
a Explain how igneous rocks were formed. [1]

b Explain why igneous rocks never contain fossils. [1]

c Give the names of two igneous rocks.

6 The diagrams below shows the sides of two quarries. The quarries are on different continents. The rocks shown are sedimentary rocks. They were built up in layers. Each layer took millions of years to form.

Fossils have been found in some of the layers. They are also shown in the diagram.



a Explain how the diagrams show that all the rocks in both quarries are sedimentary. [1]

b Give the letter of the youngest rock in Mwamba Quarry. [1]

c In which of the quarries is the oldest rock found? Explain your answer. [2]

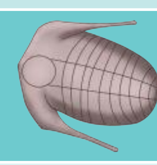
d Which rock in Batuan Quarry was formed in the same period as rock D in Mwamba Quarry? [1]

e Suggest why the number of rock layers in each quarry is different. [1]

f The fossils shown are index fossils.

i Explain what an index fossil is. [1]

ii The table below gives the index fossils for some geological time periods.

Geological time period	Index fossil
Quaternary	
Tertiary	
Devonian	
Cambrian	

Write the letters of the rocks in both quarries that were formed in the Devonian period. [1]

5.1 The states of matter revisited

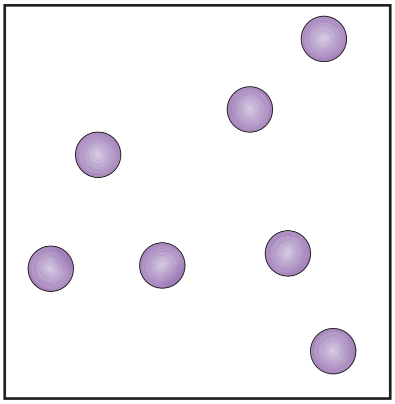
Objectives

- Describe and explain the properties of substances in their solid, liquid, and gas states
- Identify changes of state

The gas state

Oxygen is all around us, mixed with other substances in the air. Without oxygen, we could not live. Without oxygen, fuels would not burn.

In the air, oxygen exists in the gas state. Its particles move around from place to place. They do not touch each other, and spread out to fill the whole container. There are very weak forces of attraction between the particles.



Particles of a substance in the gas state.

The arrangement and behaviour of the particles in the gas state explain each of the properties below:

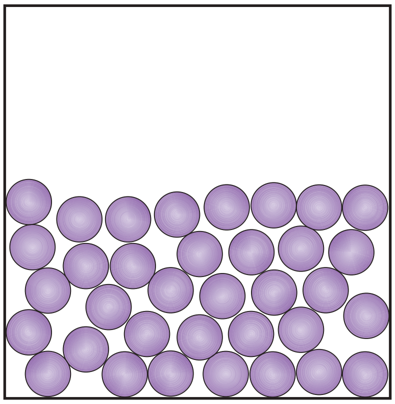
- gases fill the whole container – their volume is the same as the volume of the container
- gases take the shape of their container
- gases can flow
- gases can be compressed.

The liquid state

If oxygen is cooled to –183 °C it changes state from gas to liquid. This change of state is called condensation.

In any change of state, the particles themselves do not change. Their mass, for example, remains the same. It is only the arrangement and behaviour of the particles that change.

In the liquid state, there are strong forces holding the particles together. The particles touch each other, and there is very little empty space between them. The particles are not arranged in a regular pattern. They move around from place to place, in and out of each other.



The particles of a substance in the liquid state.

This Indian satellite launch vehicle uses liquid oxygen to help propel it into space.

The arrangement and behaviour of the particles in the liquid state explain each of the properties below:

- liquids have a fixed volume
- liquids take the shape of their container
- liquids can flow
- liquids can be slightly compressed.

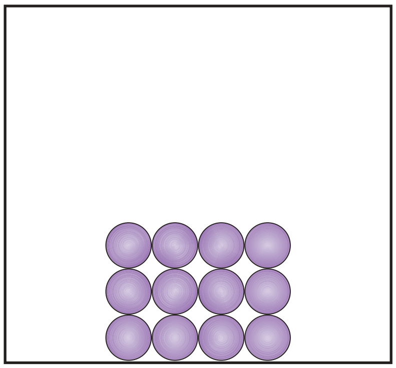
The solid state

At –218 °C, oxygen changes from the liquid state to the solid state. This change of state is called freezing.

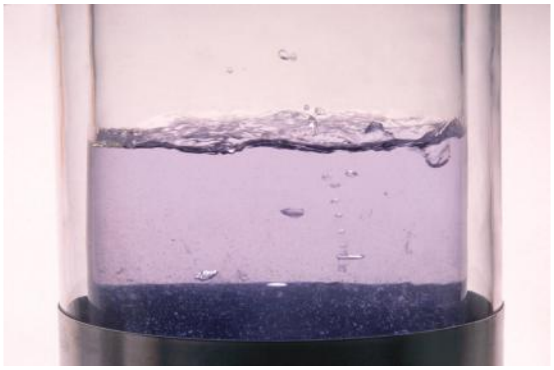
Solid oxygen behaves differently from oxygen in the gas and liquid states. Like all solids, it has the properties below:

- solids have a fixed shape and volume
- solids cannot be compressed
- solids cannot flow.

The particle theory explains the properties of substances in the solid state. The particles are arranged in a regular pattern, and cannot be any closer together. Strong attractive forces hold the particles in their pattern. The particles do not move around from place to place – they vibrate on the spot.



The particles of a substance in the solid state.



Solid oxygen is pale blue.

More changes of state

Solid oxygen changes to the liquid state when it is warmed to –218 °C. This is melting.

At higher temperatures, particles escape from the surface of liquid oxygen. Some of the liquid oxygen has changed state to form oxygen gas. This is evaporation.

At –183 °C liquid oxygen boils. In boiling, bubbles of oxygen gas form throughout the liquid. The bubbles rise to the surface and escape. Eventually, all the liquid oxygen changes state to become a gas.

Q

1. Draw circles to represent particles of oxygen in the liquid state.
2. Describe the behaviour of oxygen particles in the gas state.
3. Explain why you cannot compress oxygen in the solid state, but why you can compress oxygen in the gas state.
4. Describe how the behaviour of the particles changes when a substance changes from its solid state to its liquid state.
5. Use the information below to give the state of nitrogen at -200 °C.

	Temperature
melting point of nitrogen	-210 °C
boiling point of nitrogen	-196 °C

!

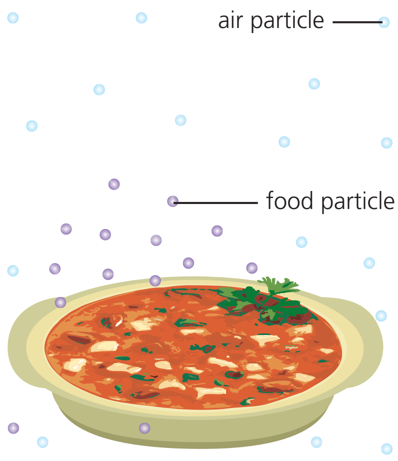
- The arrangement and behaviour of particles explains the different properties of the substance in the gas, liquid, and solid states.

5.2 Explaining diffusion

Objectives

- Use the particle theory to explain diffusion
- Describe evidence for diffusion

Diffusion



Rebekah is cooking dinner for her family. Very soon, everyone in the house can smell the food. Why?

Food particles evaporate as Rebekah is cooking. They move around randomly in the air, and spread out. The food particles mix with air particles. Soon there are food particles all over the house. Some of the food particles enter your nose, which detects the smell.

The random movement and mixing of particles is called **diffusion**. Particles move because they have energy. You do not need to move or stir to make diffusion happen.

The speed of mixing by diffusion depends on three factors:

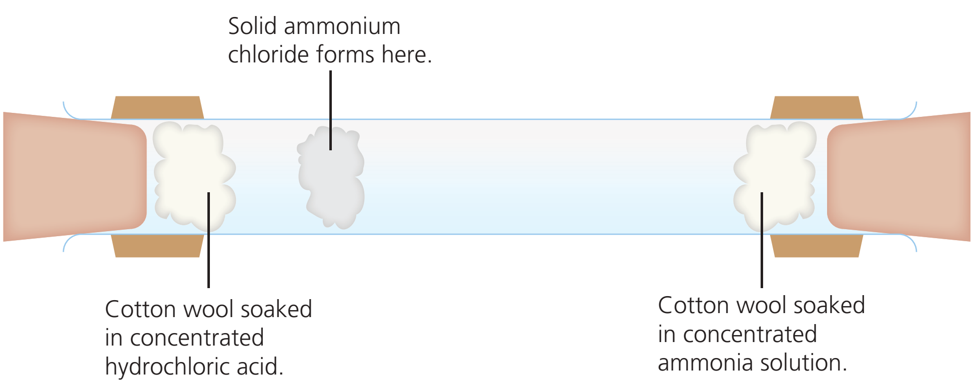
- temperature
- size and mass of the particles
- the states of the substances that are diffusing.

Diffusion and temperature

Particles from warm food diffuse more quickly than those from cool food. The warmer particles have more energy, so they move faster.

Diffusion and particle size and mass

A teacher sets up the apparatus below.



Particles of hydrogen chloride and ammonia evaporate from the cotton wool. They diffuse along the tube. When the two types of particle meet they react. This forms a new substance, which is a white solid. You can see the solid in the tube.

The solid forms closer to the cotton wool soaked in hydrochloric acid. This shows that hydrogen chloride particles diffuse more slowly than ammonia particles. A hydrogen chloride particle has a greater mass than an ammonia particle.

Big, heavy particles diffuse more slowly than smaller, lighter particles.

Diffusion in gases, liquids, and solids

Diffusion through gases

Diffusion happens quickly in a gas. This is because a particle can travel a long distance before it hits another particle.

Diffusion through liquids

Mo puts a crystal of potassium manganate(VII) in a Petri dish of water. He watches carefully. The purple colour starts to spread through the water.

The next day Mo looks at the mixture again. The purple colour has spread all through the water. Purple particles have moved away from the crystal and mixed with the water particles.

Diffusion happens more slowly in liquids than in gases. This is because particles are closer in liquids, and there are stronger forces between them.

Purple potassium manganate(VII) crystals start to diffuse through liquid water.

Diffusion in solids

Diffusion happens very slowly – if at all – in solids. This is because very strong forces hold the particles in position. However, solid diffusion can happen enough to be useful.

Solar cells generate electricity from sunlight. One type of solar cell is made from thin slices of pure silicon. When the cell is being made, phosphorus particles diffuse into the silicon. The process happens at a high temperature, just below the melting point of silicon.

Solid diffusion is used in making solar cells.

Evidence for moving particles

In 1828, Robert Brown suspended pollen grains in water. He looked at them through a microscope. The pollen grains moved around quickly. Why?

The pollen grains were pushed around by the random movements of the water particles around them. But how? Water particles are tiny compared to pollen grains. The answer lies in the speed of the water particles – on average, a water particle moves faster than 1600 km/h at 20 °C.

Q

1. Explain the meaning of the word *diffusion*.
2. List three factors that affect the speed of diffusion.
3. Explain why diffusion happens more quickly at higher temperatures.

!

- Diffusion is the random movement and mixing of particles.
- Diffusion happens faster at higher temperatures.
- Big, heavy particles diffuse slower than smaller, lighter particles.
- Diffusion is quicker in gases than in liquids. Solid diffusion is very slow.

5.3 Explaining density

Objectives

- Use a formula to calculate density
- Explain why different substances have different densities

What is density?

Ravi is a weightlifter. His dumbbells are made from iron. Why not make dumbbells from aluminium or wood?

Ravi lifts iron dumbbells. Bikram's are made from aluminium.

Iron dumbbells are heavier than aluminium dumbbells of the same size. This is because iron has a greater **density** than aluminium. Density is how heavy something is for its size. A 1 cm^3 cube of iron is heavier than a 1 cm^3 cube of aluminium.

Substance	Density (g/cm^3)
iron	7.9
aluminium	2.7
wood	about 0.5

Calculating density

Katrina has a block of lead. She wants to calculate its density. She measures:

- the mass of the block of lead
- the volume of the block of lead.

Katrina writes down her data.

Mass of block of lead = 44 g
Volume of block of lead = 4 cm^3

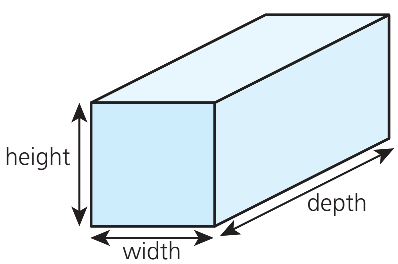
She uses this equation to calculate density:

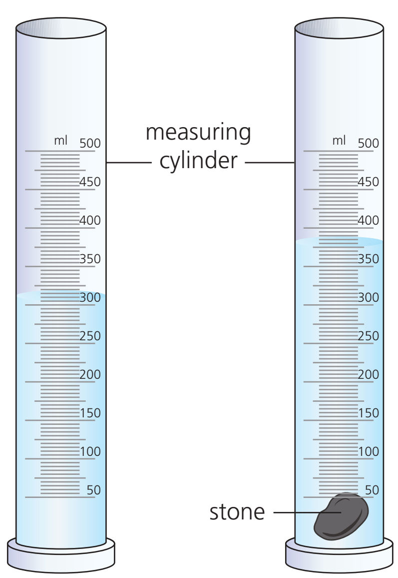
$$\textbf{density} = \frac{\textbf{mass}}{\textbf{volume}}$$

$$\text{density} = \frac{44\text{ g}}{4\text{ cm}^3}$$
$$= 11\text{ g/cm}^3$$

You can work out the volume of a sample of solid in two ways.

- If your sample is a cube or cuboid, measure the lengths of its sides. Then calculate height × width × depth.
- If your sample is of any other shape, take a known volume of water. Place the sample in the water. The volume increase is the volume of the sample.





Explaining density

The density of a substance depends on two things:

- the mass of its particles
- how closely packed its particles are.

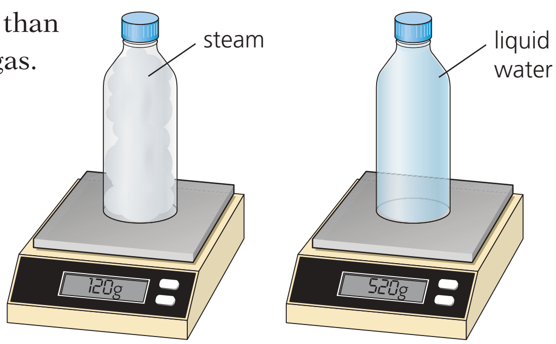
Particle mass

In the solid state, the metals with the heaviest particles have the highest densities.

Metal	Relative mass of particles	Density (g/cm^3)
cobalt	59	9
nickel	59	9
copper	63.5	9
iridium	192	23
platinum	195	21
gold	197	19

Closeness of particles

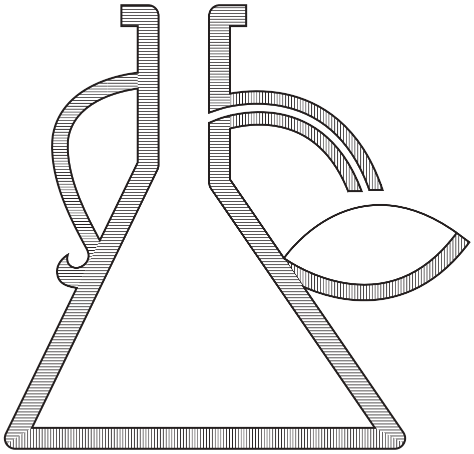
The particles of a substance in the liquid state are more closely packed than the particles in the gas state. The liquid has a greater density than the gas.



The pictures show the mass of 500 cm^3 of liquid water compared to 500 cm^3 of steam. The mass of the bottle is 20 g.

For most substances, the solid density is greater than the liquid density. This is because the solid particles are packed more closely.

Water is different. At 0 °C the particles in ice are packed less closely than the particles in liquid water. Ice has a lower density than liquid water. This explains why ice floats on water.



Al-Biruni used this apparatus to measure the volume of gemstones. He found their mass and calculated their density.

Using density

About 1000 years ago, al-Biruni of Persia studied gemstones. He collected data on their colour and hardness. He calculated their densities, and used density values to identify gems. Al-Biruni used the apparatus shown here to measure the volume of gemstones. He found their mass and calculated their density.

Ice floats on liquid water because ice has a lower density at 0 °C.

Q

1. Give the meaning of the word *density*.
2. A block of silver has a mass of 20 g and a volume of 2 cm^3. Calculate its density.
3. The mass of a particle of chromium is 52. The mass of a particle of tungsten is 184. Predict which of the two metals has the higher density. Explain your prediction.

!

- density = $\frac{\text{mass}}{\text{volume}}$
- The density of a substance depends on the mass of its particles and how closely packed its particles are.

5.4 Explaining gas pressure

Objectives

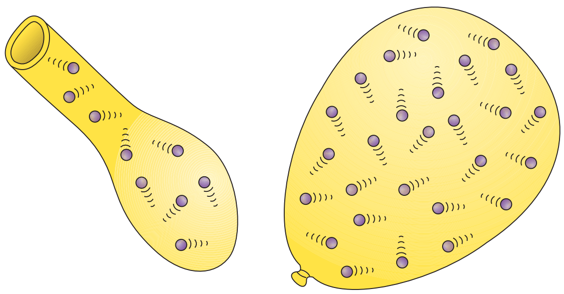
- Explain what causes gas pressure
- Explain air pressure and its effect on boiling point
- Explain how temperature affects gas pressure

Explaining gas pressure

Raj blows up a balloon. The balloon gets bigger and bigger. Why?

When Raj starts blowing, air particles enter the balloon. The particles move quickly in all directions. They bump into, or **collide** with, the rubber. The colliding particles exert a force on the rubber, and push it outwards. The force per unit area is called **pressure**.

As Raj continues blowing, more air particles enter the balloon. The balloon gets bigger.



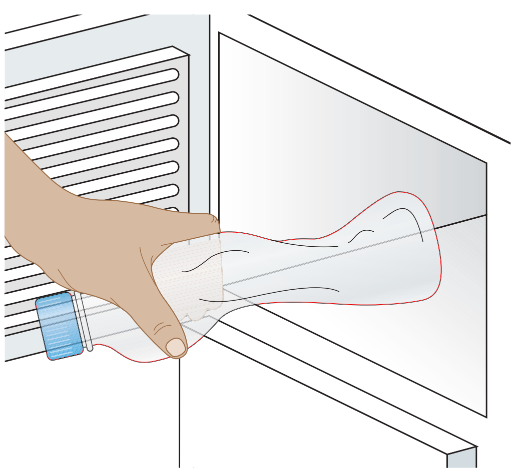
The more Raj blows into the balloon, the greater the number of air particles inside it.

How does temperature affect gas pressure?

Raj ties up his balloon. He leaves it in a warm room. The balloon gets even bigger. Why?

The air particles inside the balloon warm up. They move faster. They hit each other, and the sides of the container, more often. The air pressure inside the balloon has increased. In the warm balloon, the faster moving particles are further apart. This is why the balloon gets bigger.

Saniyah puts a plastic bottle in a freezer. The air in the bottle cools down. The particles move more slowly. They hit each other, and the inside of the bottle, less often. The pressure inside the bottle has decreased. The bottle collapses.



The bottle collapses as the air pressure inside it decreases.

Air pressure

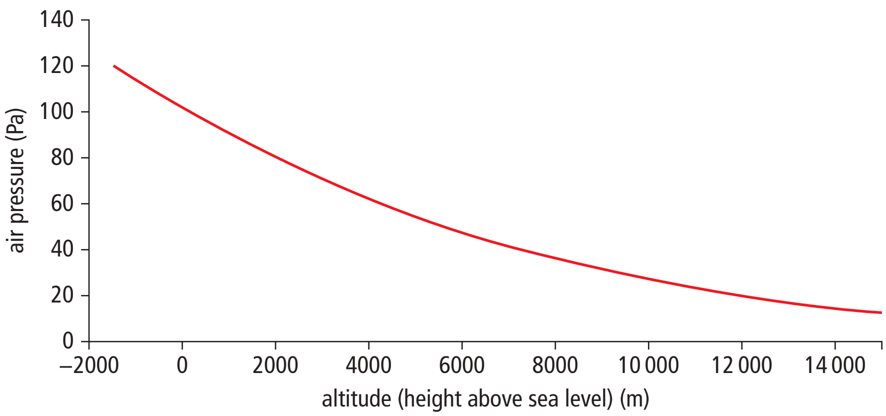
Tirto lives in Padang, a city by the sea. He visits the mountains. He feels breathless. Why?

Air particles collide with you all the time. The force exerted by these particles per unit area is **air pressure**. The pressure does not squash you because you have air inside your body too.

Air pressure depends on how high up you are. At the top of a mountain there is less air pressing down on you than there is at sea level. The air pressure is less at the top of the mountain.

At the top of the mountain, air particles are further apart than they are at sea level. You need to breathe more often to take in enough oxygen.

People who live in the mountains all the time don't breathe more often than people who live at sea level. Their bodies have adapted to the lower air pressure.



The graph shows how air pressure changes with altitude (height above sea level).

Air pressure and boiling point

Bubu heats liquid water. Water particles leave the surface of the liquid. These particles form a vapour above the liquid.

Water boils when the pressure of the vapour above the liquid is the same as the air pressure around the liquid.

This explains why boiling point changes with altitude (height above sea level). The higher the altitude, the lower the air pressure. The lower the air pressure, the lower the temperature at which the vapour pressure is equal to the air pressure.

Q

1. Gases exert pressure on the walls of a container. Explain why.
2. Shahid pumps up a bicycle tyre. Describe how the air pressure inside the tyre changes as he pumps.
3. Nadeem places a plastic bottle of air in a pan of hot water. Predict and explain how the pressure inside the bottle changes.
4. **Extension:** Use the graph to estimate the air pressure in Nairobi, altitude 1660 m.
5. **Extension:** In Asmara, a city by the sea, water boils at 100 °C. In Addis Ababa, a city 2300 m above sea level, water boils at 92 °C. Explain this difference.

!

- Gas pressure is caused by particles colliding with the walls of a container.
- The higher the temperature, the greater the gas pressure.

Enquiry 5.5

Ideas and evidence

Objective

- Understand how scientists use questions, evidence, and creative thought to develop explanations

Scientific questions

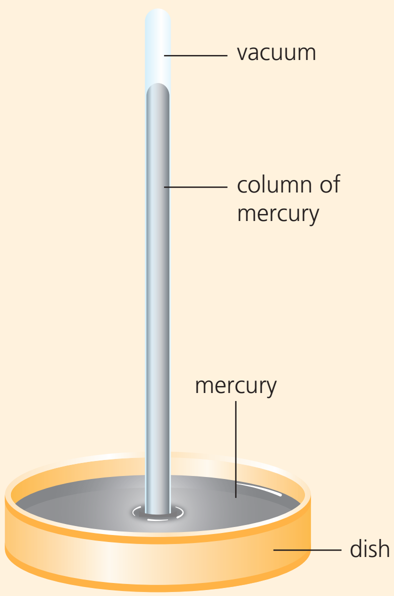
Scientists ask questions. What is matter made of? How old is the Earth? Which malaria medicine is best?

A question is scientific if doing an experiment, or making observations, will help to answer it. Scientific questions are also called **empirical questions**.

Not all questions can be answered by science. A scientist could investigate which malaria medicines work best. But she could not use science to answer the question:

Should the government provide free malaria treatment for everyone?

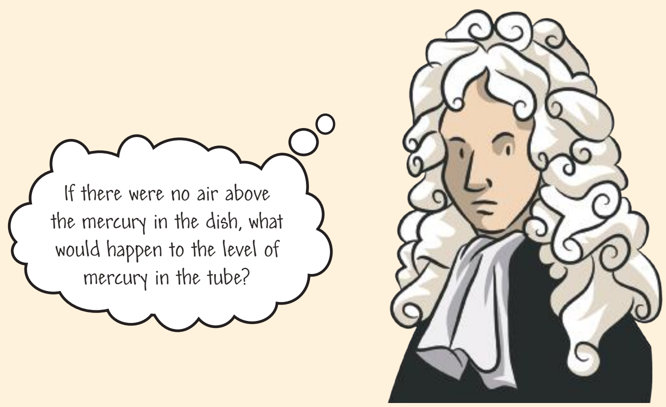
Many scientific discoveries start with questions. But others begin when scientists respond creatively to an accident or mistake. Teflon, a material used in space vehicles and artificial heart valves, was first made accidentally.



Boyle's barometer. This type of barometer was first made by Torricelli.

A question of pressure

Robert Boyle had a barometer. Sometimes the mercury was high in the tube. At other times it was lower. But the mercury level in the tube never fell below a certain minimum level. Boyle wondered why. He asked an empirical question:



Suggesting an explanation

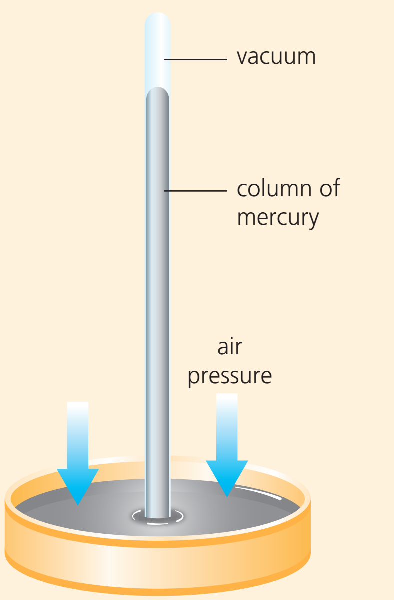
Boyle knew that another scientist, Torricelli, had explained that air pressure on the mercury in the dish supported the mercury in the tube (see diagram). Torricelli had used **creative thinking**, and experimental evidence, to come up with his explanation.

Boyle used this knowledge, and his own creative thinking, to suggest an explanation to answer his question.

Suggested explanation

If there is no air above the mercury in the dish, there will be no air pressure on the surface of this mercury. The mercury in the tube will not be supported.

Boyle used this suggested explanation to make a **prediction**. If he placed the dish of mercury in a container and pumped the air out, the mercury in the tube would fall to the level of the mercury in the dish.



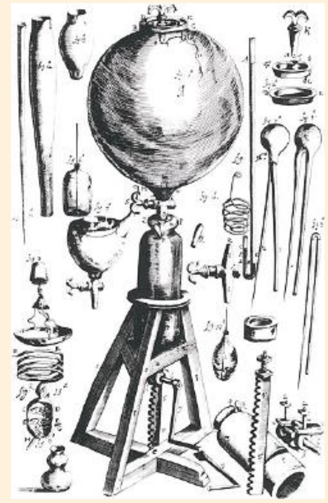
The arrows represent air pressure.

Testing the explanation

Boyle did an investigation to test his explanation. First, he and another scientist, Robert Hooke, designed and made an air pump. This took many weeks.

Next, the scientists placed the dish of mercury in the pump. The tube stuck out of the top. The scientists sealed the gap round the tube.

Then Boyle and Hooke began to pump out air. The level of mercury in the tube fell. They pumped harder. In the end, the height of the mercury column fell to 2.5 cm.



Boyle and Hooke's air pump.

Checking the evidence

Boyle discussed the investigation results with Hooke and other scientists. Was his prediction correct? Did the evidence support his suggested explanation?

Boyle concluded that the evidence supported his suggested explanation. The height of mercury in the tube did not quite fall to the level of mercury in the dish, but it came close. Small air leaks into the pump, said Boyle, meant that the mercury in the dish always experienced some air pressure.

Ask a question
If there were no air above the mercury in the dish, what would happen to the level of mercury in the tube?

↓

Suggest an explanation
If there were no air above the mercury in the dish, there will be no air pressure on the surface of this mercury. The mercury in the tube will not be supported.

↓

Test the explanation
Place the barometer in an air pump. Observe what happens to the level of mercury in the tube.

↓

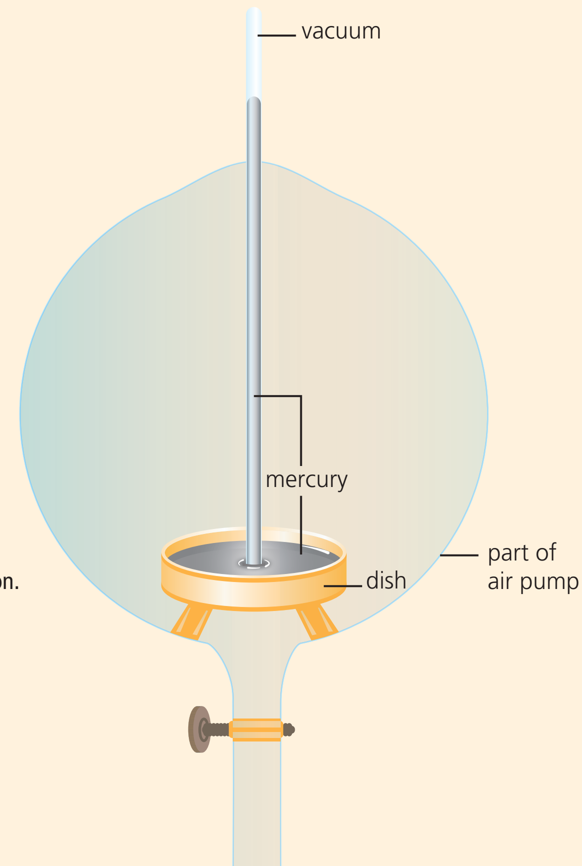
Check the evidence
Does it support the explanation?

NO → There must be a different explanation. → (back to Suggest an explanation)

↓ **YES**

The explanation is accepted.

The diagram summarises the steps in developing a scientific explanation.



A simplified diagram of Boyle and Hooke's apparatus

Q

1. What is an empirical question?
2. Scientists collect evidence and make observations to help answer a scientific question. What else do they do?
3. Explain why scientists collect evidence and make observations.
4. A scientist collects evidence. It does not support his suggested explanation. Suggest what the scientist might do next.

!

To develop explanations, scientists:

- ask empirical questions
- think creatively to suggest an explanation
- collect evidence and make observations.

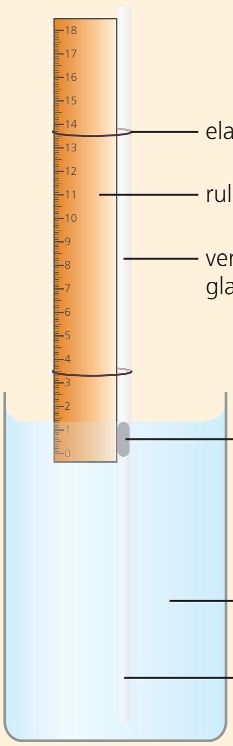
Enquiry

5.6 Doing an investigation

Objectives

Understand how to:

- plan an investigation
- obtain and present evidence
- consider evidence



Apparatus to investigate how the volume of air varies with temperature.

Planning an investigation

Azibo wants to find out if there is a relationship between the temperature of air and its volume. He plans an investigation.

First, Azibo identifies important variables. He decides which to change and measure:

- variable to change – temperature
- variable to measure – volume of air.

Azibo wants his investigation to be a fair test. He keeps the other important variable – air pressure – constant.

Azibo chooses his apparatus, because the experiment uses concentrated sulfuric acid Azibo's teacher will perform the experiment for him. Concentrated sulfuric acid is very corrosive and dangerous to use. Azibo's plan is to measure the height of the air column at six different temperatures. He will then calculate the volume of air at each temperature.

Before the experiment starts, Azibo makes a prediction. He knows that heating a gas makes its particles move faster and get further apart. He uses this scientific knowledge to predict that heating the gas in the tube will make its volume increase. Cooling the gas, predicts Azibo, will reduce its volume.

Presenting evidence

Azibo draws a table for the results. He writes the variable he changes in the left column, and the variable he measures in the next column. He includes units in each column heading.

Azibo collects his data whilst his teacher is carrying out the experiment. He writes them in the table.

Temperature (°C)	Height of column (mm)
2	1
17	18
20	24
26	33
30	46
37	60

Considering evidence

Doing calculations

Azibo needs to calculate the volume of air at each temperature. He uses the equation below:

volume = 80 mm^3 + [height (mm) × cross sectional area of tube (mm^2)]

volume = 80 mm^3 + [height (mm) × 0.8 mm^2]

He adds a column to his table.

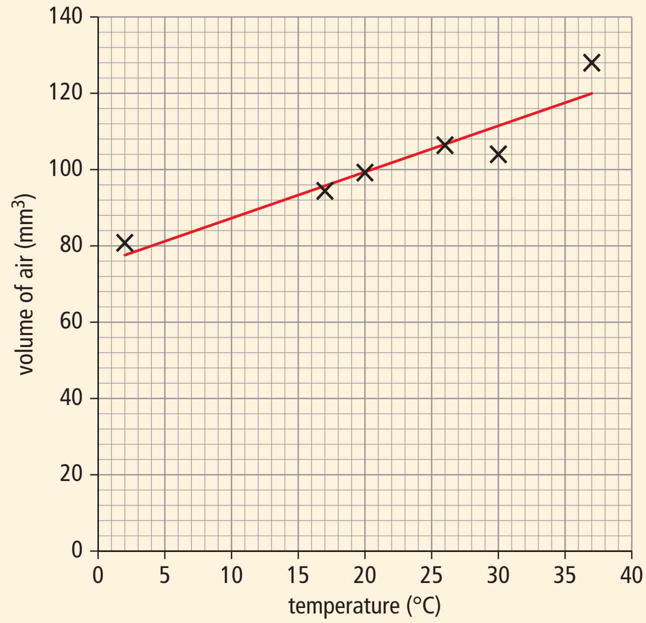
Temperature (°C)	Height of column (mm)	Volume of air (mm^3)
2	1	80.8
17	18	94.4
20	24	99.2
26	33	106.4
30	46	104.0
37	60	128.0

Identifying trends and patterns

Azibo can see from his table that his results show a pattern – as temperature increases, gas volume increases. But Azibo wants to look more closely at the pattern. He plots the points on a graph, and draws a line of best fit.

The graph shows that as temperature increases, gas volume increases steadily. This relationship is an example of a **correlation** between two variables.

Azibo looks back at his prediction. It was correct! This makes him more confident that the science explanation on which he based his prediction is correct.



Graph showing how the volume of a gas varies with temperature at constant pressure.

Identifying anomalous results

Azibo looks at his results again. One of the points on the graph is not near the line of best fit. The result for 30 °C is **anomalous**.

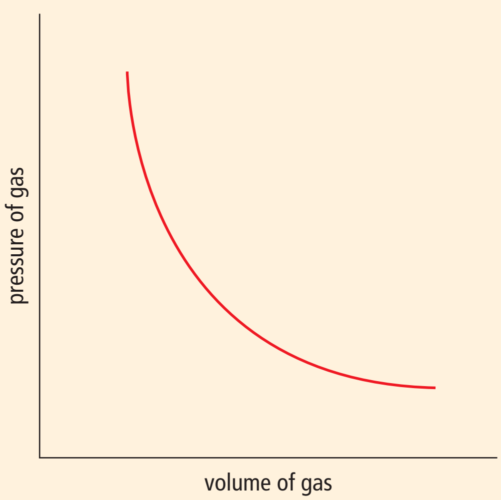
Azibo wants to find out why this result is anomalous. He repeats the experiment at 30 °C. The height of the column is 46 mm. Azibo has not made a mistake when collecting data.

Azibo checks his calculation. He has made a mistake. For a height of 46 mm, the volume should be 116.8 mm^3. He plots this point on his graph. It is close to the line of best fit.

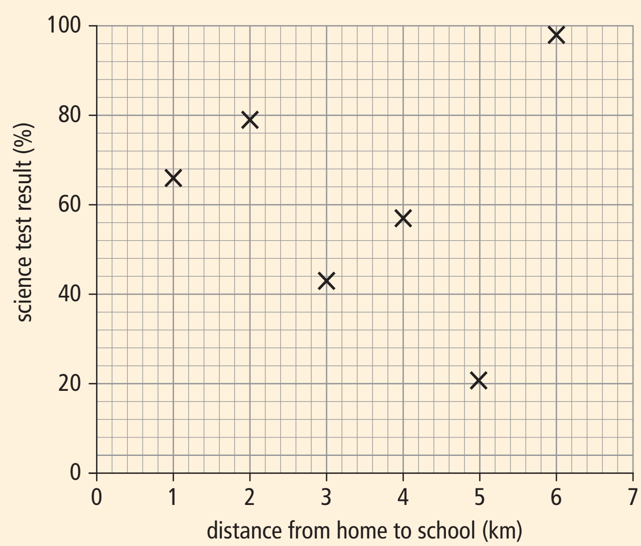
Another correlation

Graph A, below, shows a correlation between two variables.

Graph B does not show a correlation.



Graph A.



Graph B. There is no correlation between the distance a student lives from school, and their science test results.

Q

1 Why does Azibo keep the air pressure constant in his investigation?

2 Describe the correlation shown on graph A.

3 Marcos does a similar investigation to Azibo. He measures the volume at 6 temperatures between 0 °C and 60 °C. Explain how Marcos's investigation is better than Azibo's.

!

Doing an investigation involves:

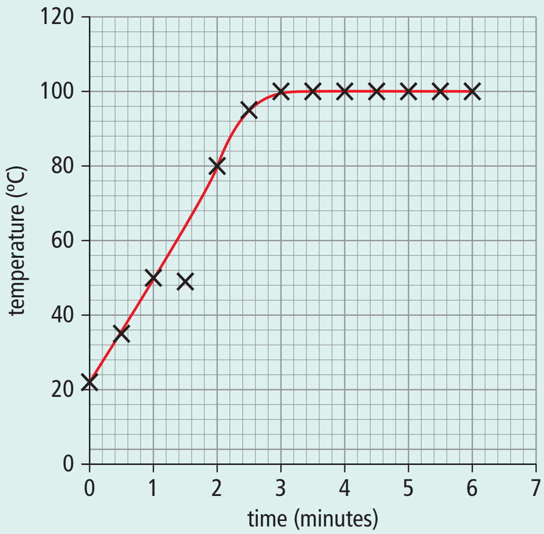
- planning
- obtaining and presenting evidence
- considering the evidence.

Review 5.7

1 Copy and complete the table to show the properties of a substance in the solid, liquid, and gas states. [8]

property	solid	liquid	gas
volume		fixed volume	
shape			same as container
can it flow?		yes	
can it be compressed?			yes

2 A student heated some liquid water. He recorded the temperature of the water every minute. He plotted a graph of his results.

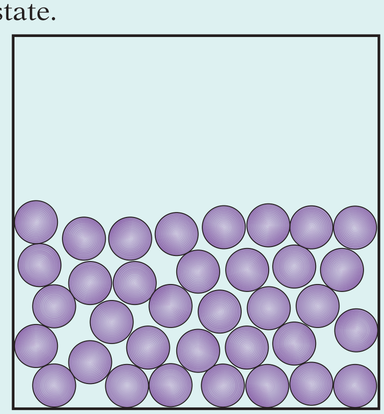


a Name the change of state that is happening between the third and sixth minutes. [1]

b Identify the anomalous result shown on the graph. [1]

c Suggest one mistake the student might have made to get this anomalous result. [1]

3 The diagram shows the particles of a substance in its liquid state.



a What could you do to make the particles in the liquid move more quickly? [1]

b Draw a diagram to show the same particles after the liquid has evaporated. [1]

c Describe the movement of the particles after the liquid has evaporated. [1]

4 Copy and complete the sentences below using words from the list. You may use the words once, more than once, or not at all.

bigger than **smaller than** **the same as**

a The size of one particle in liquid mercury is __________ the size of one particle in solid mercury. [1]

b In liquid mercury the distance between the particles is __________ the distance between the particles in mercury gas. [1]

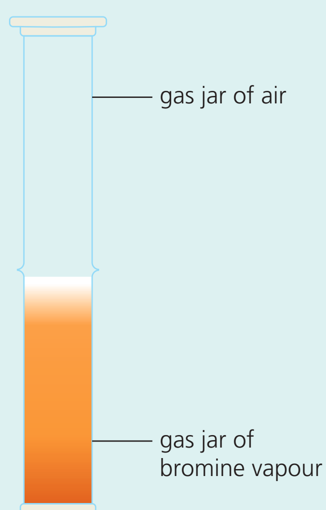
c The forces between the particles in liquid mercury are __________ the forces between the particles in solid mercury. [1]

5 Copy these and draw lines to match each property with the best explanation.

Property	Explanation
You cannot compress a solid.	The particles move around, in and out of each other.
If a gas is in a container with no lid, it escapes from the container.	There is no empty space between the particles.
A liquid takes the shape of the bottom of its container.	Its particles are in fixed positions.
A solid cannot be poured.	The particles move around in all directions.

[3]

6 A teacher sets up the apparatus below. She leaves it in a hot room, at 30 °C.



a One hour later, the teacher observes an orange vapour in both gas jars. Explain why. [1]

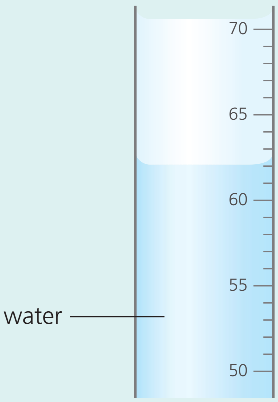
b The teacher sets up exactly the same apparatus again. She leaves the jars in a cooler room, at 15 °C.

i Predict one difference in her observations at the two temperatures. [1]

ii Use ideas about particles to explain this difference. [2]

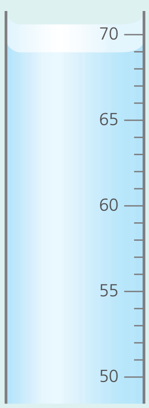
7 Pawel has a stone. He wants to find its density.

a He pours water into a measuring cylinder until it is half full. The diagram shows the surface of the water. Write down the water volume in cm^3.



[1]

b Pawel places the stone in the water. The water surface of the water moves up. The diagram shows the new surface of the water.

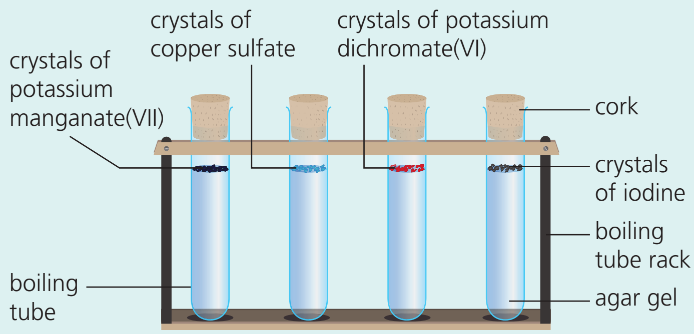


Use the diagram, and your answer to part (a) to work out the volume of the stone. [1]

c The mass of the stone is 11.5 g. Use the equation below to calculate the density of the stone. Include units in your answer.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$ [2]

8 Pippa investigates the speed of diffusion of four coloured substances in agar gel. She plans to set up the apparatus below.



a Pippa lists the important variables in her investigation.

type of agar gel
temperature of agar gel
substance that diffuses
distance from top of agar gel to bottom of colour
time for which the solids are left to diffuse

i Choose the variable in the list above that Pippa should change. [1]

ii Choose the variable in the list above that Pippa should measure. [1]

iii Pippa must control the other variables in the list. Explain why. [1]

b Potassium dichromate(VI) is very toxic if swallowed. It can also cause skin ulcers. Suggest how Pippa can reduce the risk from each of these hazards. [2]

c Draw a table for Pippa's results. Include units in the column headings, if necessary. [2]

d Pippa decides to do the whole investigation twice more. She writes down the distance from the top of the agar to the bottom of the iodine colour in each investigation.

First time – 0.5 cm
Second time – 0.6 cm
Third time – 0.4 cm

Pippa then calculates the average distance for iodine.

i Suggest why Pippa repeated the investigation three times, and calculated an average. [1]

ii Suggest why the distance was different in each investigation. [1]

6.1 Atoms

Objectives

- Explain what an element is
- Explain what an atom is
- Understand the importance of questions, evidence, and creative thought in developing explanations

Zinc – a vital element

In the late 1950s, Professor Ananda Prasad moved to Iran from his home in India. A 21-year-old man visited Professor Prasad. He had not grown properly, and looked like an eight-year-old boy. Many other Iranians had the same condition.

Professor Prasad asked a question. What was the cause of the condition? He knew that plants needed zinc to grow. Did humans need zinc too?

Professor Prasad decided to test his idea. He collected evidence in Iran and Egypt. By 1963 he had an answer. A shortage of zinc causes growth problems.

People who eat mainly cereals and beans, or cassava and potatoes, risk zinc deficiency. In Indonesia, Mexico, and Peru, zinc chemicals are added to flour.

Atoms and elements

Zinc is an element. Like all elements, it cannot be split into anything simpler. There are 92 elements found naturally on Earth. Scientists have made at least 25 more.

Elements are made up of particles called **atoms**. An atom is the smallest part of an element that can exist. Atoms are tiny. The diameter of one atom is about 0.000 000 01 cm. If you could place one hundred million atoms side by side, they would stretch one centimetre.

Every element has its own type of atom. The atoms of each element are different from the atoms of every other element. So all zinc atoms are alike, but zinc atoms are different from copper atoms, gold atoms, and iron atoms.

Imagining atoms

Toy bricks can help us imagine atoms.

If these bricks represent oxygen atoms...

...then these represent atoms of another element, like nitrogen.

If these bricks represent gold atoms...

...then this shows a piece of gold.

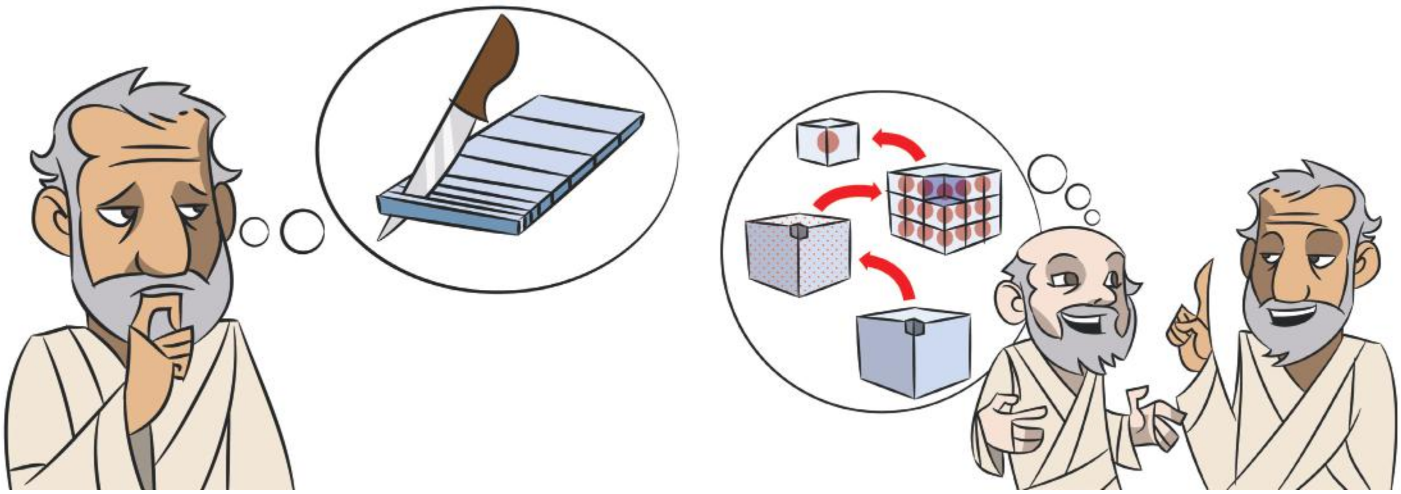
Of course the toy brick model is not perfect. Atoms do not have straight edges. And atoms are much, much, much smaller than the toy bricks.

Atoms – ideas and evidence

Ideas about atoms are not new. More than 2500 years ago, Greek thinkers asked a question. Could you go on cutting a piece of matter into smaller and smaller pieces for ever?

Zeno answered 'yes'. He said that matter completely fills its space. So you can keep cutting it into smaller pieces for ever.

Leucippus and Democritus thought differently. They said that matter is divided into tiny separate bits – atoms – with empty space between. They believed that atoms are the smallest pieces of matter that exist.



At least a thousand years ago, Indian thinkers developed ideas about atoms. They described four elements. Each element had its own type of atom. Atoms, they said, could not be split up.

As far as we know, the Greek and Indian thinkers did not do practical experiments. They used creative thought to answer their questions.

Evidence for atoms came later. In the 1660s, Robert Boyle used ideas about atoms to explain experimental observations. Around the year 1800, John Dalton collected evidence from his own investigations, and from other scientists. He thought about the evidence. It supported the explanation that matter is made up of atoms.

Q

1. What is an atom?
2. What is an element?
3. Are the atoms in a piece of gold the same as, or different from, each other?
4. Are oxygen atoms the same as, or different from, gold atoms?

!

- An element is a substance that cannot be split into anything simpler.
- An atom is the smallest part of an element that can exist.
- Scientists ask questions, collect evidence, and think creatively to develop explanations.

6.2 Elements and their symbols

Objectives

- Know the chemical symbols of the first twenty elements of the periodic table
- Understand why scientists use symbols for elements

Symbols for the elements

Some elements have long names. So each element has its own **chemical symbol**. It's much easier to write Pr than praseodymium!

Often, the chemical symbol is the first one or two letters of an element's name in English. The table gives some examples:

Element	Chemical symbol
carbon	C
calcium	Ca
cobalt	Co
nitrogen	N
neon	Ne
nickel	Ni

Sometimes the chemical symbol is made up from the first and third letters of the English name of an element. For example:

Element	Chemical symbol
magnesium	Mg
manganese	Mn
chromium	Cr
chlorine	Cl

The chemical symbols for some elements come from other languages:

- the chemical symbol for iron, Fe, comes from the Latin name for iron, *ferrum*.
- the chemical symbol for tungsten, W, comes from the German name for tungsten, *wolfram*.

Scientists all over the world use the same chemical symbols. All scientists recognise S as the chemical symbol for sulfur, even though it's called *belerang* in Indonesian, كبريت (kibrit) in Arabic, *soufre* in French and *azufre* in Spanish.

Writing chemical symbols

Follow these rules to write chemical symbols correctly:

- Write a capital letter for a one-letter symbol. For example, the chemical symbol for nitrogen is N, not n.
- Write a capital letter followed by a lower-case letter for a two-letter symbol. For example, the chemical symbol for magnesium is Mg, not mg or MG.

Chemical symbols in the periodic table

The periodic table lists all the elements. The periodic table on the next page gives their names and chemical symbols. You need to learn the chemical symbols of the first 20 elements, from hydrogen to calcium.

			H hydrogen														He helium
Li lithium	Be beryllium											B boron	C carbon	N nitrogen	O oxygen	F fluorine	Ne neon
Na sodium	Mg magnesium											Al aluminium	Si silicon	P phosphorus	S sulfur	Cl chlorine	Ar argon
K potassium	Ca calcium	Sc scandium	Ti titanium	V vanadium	Cr chromium	Mn manganese	Fe iron	Co cobalt	Ni nickel	Cu copper	Zn zinc	Ga gallium	Ge germanium	As arsenic	Se selenium	Br bromine	Kr krypton
Rb rubidium	Sr strontium	Y yttrium	Zr zirconium	Nb niobium	Mo molybdenum	Tc technetium	Ru ruthenium	Rh rhodium	Pd palladium	Ag silver	Cd cadmium	In indium	Sn tin	Sb antimony	Te tellurium	I iodine	Xe xenon
Cs caesium	Ba barium	La lanthanum	Hf hafnium	Ta tantalum	W tungsten	Re rhenium	Os osmium	Ir iridium	Pt platinum	Au gold	Hg mercury	Tl thallium	Pb lead	Bi bismuth	Po polonium	At astatine	Rn radon
Fr francium	Ra radium																

Note: This periodic table does not include all the elements.

Two interesting elements

Platinum

Platinum is a silvery-white element. Its chemical symbol is Pt. Platinum is a metal, so it conducts electricity well. It is shiny, and is not damaged by air or water.

Platinum jewellery is very attractive. South Americans made platinum jewellery about 2000 years ago. The Egyptians also made jewellery and decorative boxes out of platinum. Princess Shepenupet was buried with a platinum box about 2700 years ago.

Now, computer hard disks store information in layers of platinum and cobalt. Platinum in catalytic converters reduces pollution from cars.

Ancient South American gold and platinum jewellery.

Tantalum

Tantalum has the chemical symbol Ta. It is shiny. Acids do not damage it. Tantalum is a good conductor of electricity.

Tantalum capacitors store electrical energy in cell phones and computers.

Q

1 Give the chemical symbols of these elements: hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon.

2 Give the names of the elements with these chemical symbols: Na, Mg, Al, Si, P, S, Cl, Ar, K, Ca.

3 **Extension:** Describe the properties of platinum, and list three uses of the metal.

!

- Each element has its own chemical symbol.

Extension

6.3

Discovering the elements

Objective

- Understand some factors that influenced when elements were discovered

Early ideas about elements

For thousands of years, thinkers thought about elements. They wanted to know about the simple substances that make up everything else.

More than 2000 years ago, a Greek thinker created an explanation. He said there were four elements – air, water, fire, and earth. This idea was popular for hundreds of years. Scientists in India used the explanation to help develop their ideas about atoms.

From about 1700, scientists realised that the idea of four elements was wrong. They looked for substances that did not break down into simpler substances. They already knew about some of them…

The first discoveries

Some elements exist naturally on their own. Early humans saw sulfur near volcanoes. They made charcoal by burning wood. They found gold in stream beds.

Sulfur on Ijen volcano in East Java, Indonesia.

Charcoal is a type of carbon. It forms when wood burns.

This gold headdress was made over 4000 years ago. It was found in a grave in Ur, modern Iraq.

The people of the Indus Valley started using bronze about 5000 years ago.

Copper can also exist on its own, but most copper is found joined to other elements in rocks. People started extracting copper from its rock 7000 years ago. They used copper to make weapons, tools, and jewellery.

Most early copper was extracted from malachite.

Later, people mixed copper with tin to make bronze. The properties of bronze mean that it makes excellent swords and knives.

People first extracted iron from rock about 3500 years ago. They made tools and weapons from the iron.

These iron tools are from around Europe.

1200–1700 – zinc and phosphorus

It is not easy to get zinc from its rock. However, when it is heated to high temperatures zinc evaporates easily, and escapes to the air. Indian scientists solved this problem 800 years ago. They heated zinc-containing rock with waste wool in closed containers.

Hennig Brandt made the first phosphorus. He evaporated water from urine. He heated the solid that remained until it was red hot. Phosphorus vapour evaporated.

The 1700s – elements from the air, and more metals

Scientists discovered 17 new elements in the 1700s. They isolated nickel from rocks and magnesium from pond water. They separated oxygen and nitrogen from the air.

Henry Cavendish and Joseph Priestley removed oxygen from the air. They put a mouse in the remaining air. It died. Another scientist, Daniel Rutherford, explained the evidence. He said that air is mainly nitrogen.

The 1800s – technology drives discoveries

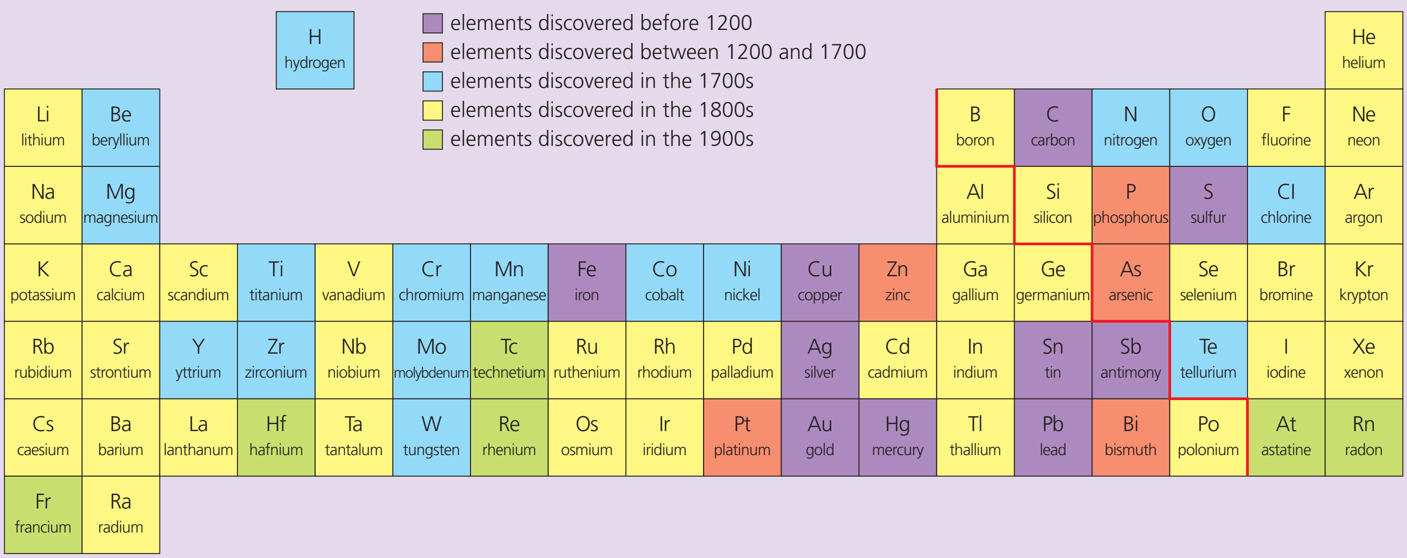
The 1880s saw the discovery of more than 50 elements. A new piece of equipment, the spectroscope, helped scientists to discover caesium and rubidium.

Aluminium was also found in the 1800s. It wasn't found earlier because it is strongly joined to oxygen in its rock.

The twentieth and twenty-first centuries

The last gaps in the periodic table were filled in the 1920s. Ida Tacke and her colleagues discovered the elements rhenium and technetium.

Scientists made more than 25 artificial elements in the twentieth century. Russian and American scientists created element 117 in the early 2000s.



Note: This periodic table does not include all the elements.

The colours in this periodic table show when the elements were discovered.

Q

1 Explain why people have known of sulfur, gold, and carbon for hundreds of years.

2 Use the periodic table to list five elements discovered between 1200 and 1700.

3 Name the two naturally-occurring elements that were discovered in the 1900s.

!

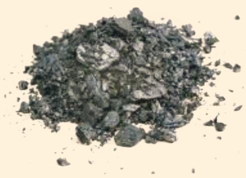
- Elements that are found on their own, not joined to other elements, were discovered first.
- Other elements were discovered as technology developed.

Enquiry 6.4

Organising the elements

Objective

- Explain how scientists asked questions, collected evidence, and thought creatively to develop the periodic table



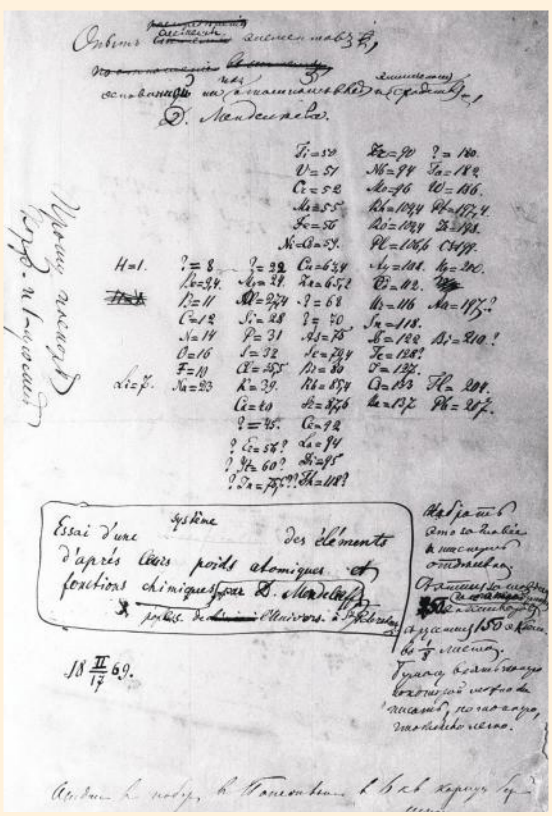
iodine

copper

copper sulfate

sulfur

Some of the 60 elements that had been discovered by 1860.



Mendeleev's first periodic table.

Asking empirical questions

By 1860 scientists had found about 60 elements. They asked questions about the elements:

- What are the patterns in the properties of elements?
- How many more elements are there?
- Can we use patterns in properties to help find new elements?

These questions are empirical questions. Scientists could do experiments and make observations to help answer them.

But scientific evidence alone would not be enough to answer the questions. Creative thinking would be vital too.

Scientists hoped to develop an explanation to answer the questions. They wanted to use their explanation to make predictions, too.

Collecting evidence and suggesting an explanation

For many years, scientists did experiments and made observations to collect evidence about the properties of elements.

In the early 1800s, John Dalton studied evidence from experiments. He suggested that elements are made from atoms. Atoms of each element have a different mass, he said. Later, another scientist worked out these masses.

Many scientists worked on finding patterns in the elements. It was the Russian scientist Dmitri Mendeleev who, in 1869, first grouped the elements in the way we still use today.

Mendeleev made lots of small cards. On each card he wrote the name of an element, its properties, and the mass of one of its atoms. He started arranging the cards in different ways.

Eventually Mendeleev came up with an arrangement that worked. He put the elements in order of the mass of their atoms, from smallest to largest. He also grouped together elements with similar properties.

Mendeleev wrote the arrangement on the back of an envelope. This was the first periodic table.

Mendeleev was confident in his explanation. It explained what scientists knew about elements. He could also use it to make predictions. Mendeleev left gaps in his table where he was sure that an element should exist, even if it hadn't been discovered. He also used his table to predict the properties of these missing elements.

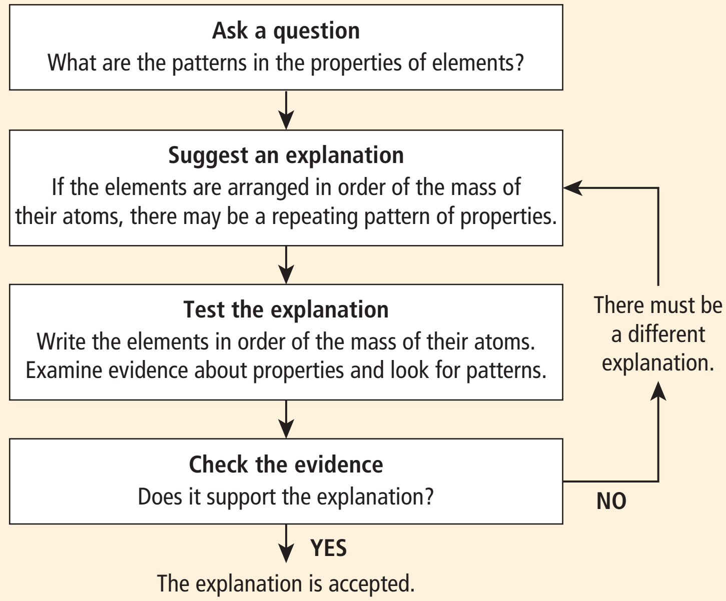
Testing the explanation and checking the evidence

Other scientists tested the explanation. They tried to find the elements that Mendeleev had predicted.

In 1874 a French scientist found one of the missing elements. He discovered the element under aluminium, and called it gallium. The properties of gallium were those predicted by Mendeleev.

Swedish and German scientists soon discovered two more of Mendeleev's missing elements – scandium and germanium.

The evidence showed that Mendeleev's predictions were correct. Scientists were confident in his great explanation. The periodic table is the foundation of modern chemistry.



This diagram summarises how Mendeleev and other scientists developed the periodic table.

族	I A	II A	III B	IV B	V B	VI B	VII B	VIII			I B	II B	III A	IV A	V A	VI A	VII A	0
1	1 H 氫																	2 He 氦
2	3 Li 鋰	4 Be 鈹											5 B 硼	6 C 碳	7 N 氮	8 O 氧	9 F 氟	10 Ne 氖
3	11 Na 鈉	12 Mg 鎂											13 Al 鋁	14 Si 硅	15 P 磷	16 S 硫	17 Cl 氯	18 Ar 氬
4	19 K 鉀	20 Ca 鈣	21 Sc 鈧	22 Ti 鈦	23 V 釩	24 Cr 鉻	25 Mn 錳	26 Fe 鐵	27 Co 鈷	28 Ni 鎳	29 Cu 銅	30 Zn 鋅	31 Ga 鎵	32 Ge 鍺	33 As 砷	34 Se 硒	35 Br 溴	36 Kr 氪
5	37 Rb 銣	38 Sr 鍶	39 Y 釔	40 Zr 鋯	41 Nb 鈮	42 Mo 鉬	43 Tc 鎝	44 Ru 釕	45 Rh 銠	46 Pd 鈀	47 Ag 銀	48 Cd 鎘	49 In 銦	50 Sn 錫	51 Sb 銻	52 Te 碲	53 I 碘	54 Xe 氙
6	55 Cs 銫	56 Ba 鋇	57– 71 鑭系	72 Hf 鉿	73 Ta 鉭	74 W 鎢	75 Re 錸	76 Os 鋨	77 Ir 銥	78 Pt 鉑	79 Au 金	80 Hg 汞	81 Tl 鉈	82 Pb 鉛	83 Bi 鉍	84 Po 釙	85 At 砹	86 Rn 氡
7	87 Fr 鍅	88 Ra 鐳	89– 103 錒系	104 Rf 鑪	105 Db 𨧀	106 Sg 𨭎	107 Bh 𨨏	108 Hs 𨭆	109 Mt 䥑	110 Ds 鐽	111 Rg 錀	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Scientists all over the world use the periodic table. This one is from a Chinese text book.

Q

1. Mendeleev used evidence to help develop the periodic table. What else did he use?
2. List three types of evidence that Mendeleev used to help develop the periodic table.
3. Write down one question that Mendeleev's periodic table helped to answer.
4. Suggest why other scientists accepted Mendeleev's periodic table as an explanation of the patterns of the properties of the elements.

!

- Scientists asked questions, collected evidence, and used creative thought to develop of the periodic table.

Enquiry 6.5

Interpreting data from secondary sources

Objective

- Practise interpreting secondary data

Element	Melting point (°C)
fluorine	–220
chlorine	–101
bromine	–7
iodine	114

Data for Group 7.

Patterns in the properties of elements

Yara and Mallana are looking for patterns in the properties of elements in the periodic table.

They do not do experiments themselves. They collect data from a data book. The data book is a secondary source.

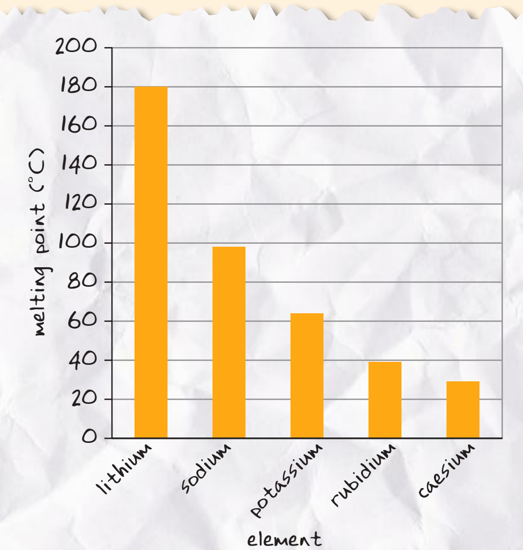
Element	Melting point (°C)
lithium	180
sodium	98
potassium	64
rubidium	39
caesium	29

Data for Group 1.

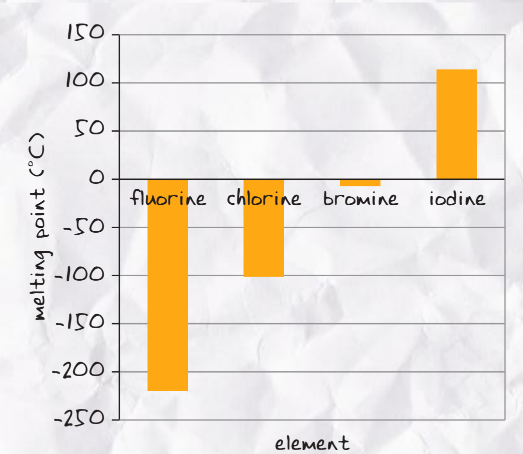
Melting point patterns

The vertical columns in the periodic table are called **groups**. The students collect data about the elements in Groups 1 and 7.

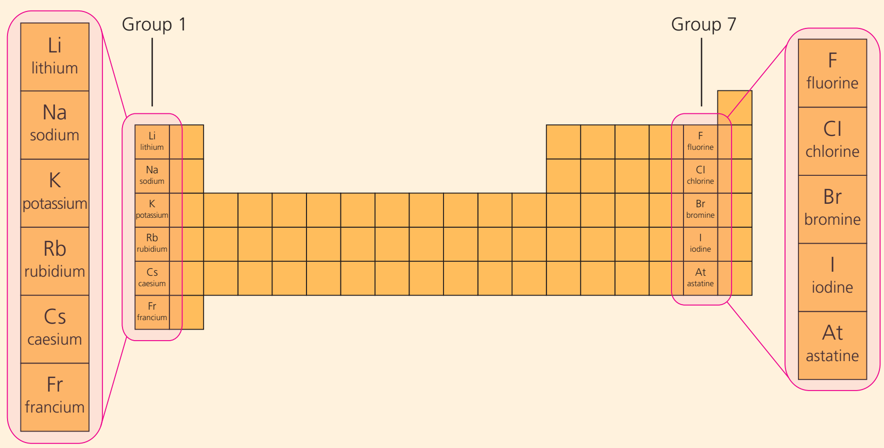
The students present the data in bar charts. They choose bar charts because the variable they change (the element) is discrete – its values are words.



The melting points of the Group 1 elements.

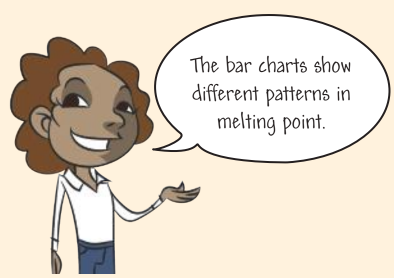


The melting points of the Group 7 elements.

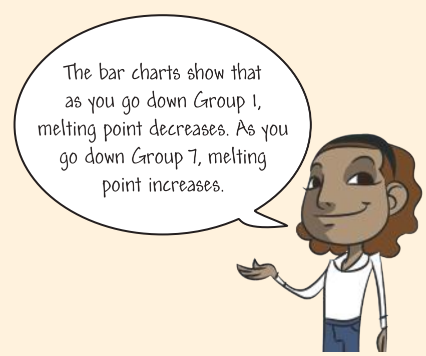


This outline periodic table shows the positions of Groups 1 and 7.

The students interpret the data. Whose interpretation is better?



Mallana



Yara

Both students give correct interpretations. Yara's is better because she interprets each bar chart separately. Yara also gives more detail.

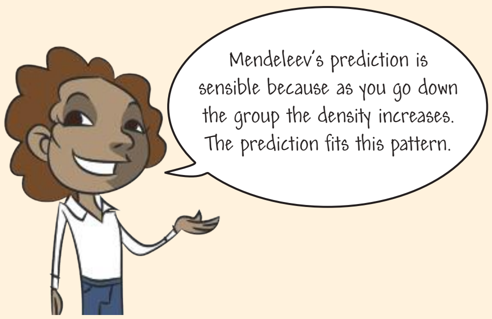
Density patterns

Mendeleev developed the periodic table. He predicted the density of an element that had not been discovered. The element is below silicon in the periodic table.

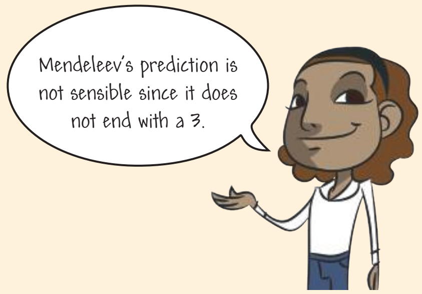
Yara and Mallana write down the densities of the other elements in the same group.

Element	Density (g/cm^3)
carbon (graphite)	2.3
silicon	2.3
undiscovered element	5.5 (predicted by Mendeleev)
tin	7.3
lead	11.3

The students interpret the data. Whose interpretation is better?



Mallana

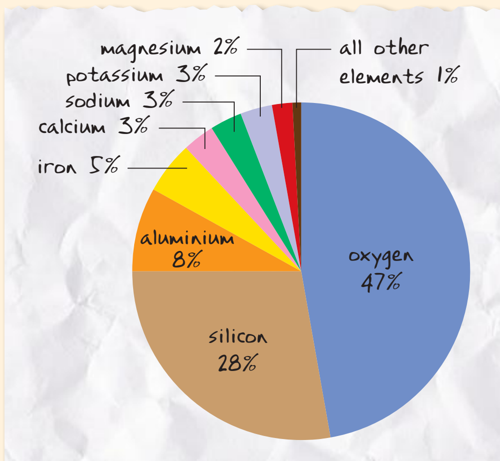


Yara

Mallana's interpretation is better. She thinks about the complete density values, not just the number to the right of the decimal point.

The elements of the Earth's crust

Haki uses a secondary source – his text book – to find out the percentages of the elements in the Earth's crust. He displays his findings in a pie chart.



The elements of the Earth's crust.

Q

1. Use the pie chart to name the three elements that are most abundant in the Earth's crust.
2. Haki makes a conclusion from his pie chart. He says there is no tin in the Earth's crust. Do you think he is correct? Give a reason for your decision.
3. Use the bar charts on the opposite page to compare the melting points of the Group 1 elements with the melting points of the Group 7 elements.

!

- When interpreting data, describe patterns and trends in as much detail as possible.

6.6 Explaining differences between metals and non-metals

Objectives

- Describe differences between metals and non-metals
- Explain differences between metals and non-metals

Metals and non-metals in the periodic table

Most elements are metals. Some are non-metals. In the periodic table:

- the elements to the left of the stepped line are metals
- the elements to the right of the stepped line are non-metals.

			H hydrogen														He helium
Li lithium	Be beryllium											B boron	C carbon	N nitrogen	O oxygen	F fluorine	Ne neon
Na sodium	Mg magnesium											Al aluminium	Si silicon	P phosphorus	S sulfur	Cl chlorine	Ar argon
K potassium	Ca calcium	Sc scandium	Ti titanium	V vanadium	Cr chromium	Mn manganese	Fe iron	Co cobalt	Ni nickel	Cu copper	Zn zinc	Ga gallium	Ge germanium	As arsenic	Se selenium	Br bromine	Kr krypton
Rb rubidium	Sr strontium	Y yttrium	Zr zirconium	Nb niobium	Mo molybdenum	Tc technetium	Ru ruthenium	Rh rhodium	Pd palladium	Ag silver	Cd cadmium	In indium	Sn tin	Sb antimony	Te tellurium	I iodine	Xe xenon
Cs caesium	Ba barium	La lanthanum	Hf hafnium	Ta tantalum	W tungsten	Re rhenium	Os osmium	Ir iridium	Pt platinum	Au gold	Hg mercury	Tl thallium	Pb lead	Bi bismuth	Po polonium	At astatine	Rn radon
Fr francium	Ra radium																

metals **non-metals**

Note: This periodic table does not include all the elements.

Properties of metals and non-metals

The table shows the properties of typical metal and non-metal elements. Their properties are described in more detail on pages 26–31.

Property	Metals	Typical non-metals
Melting point and boiling point	High – all metals, except mercury, are in the solid state at 20 °C.	Low – many are in the gas state at 20 °C. Bromine is liquid. A few are low-melting point solids. Carbon is an exception – it has a high boiling point.
Appearance	Shiny.	The solids are dull.
Conduction of electricity	Good conductors.	All are poor conductors, except graphite (a form of carbon).
Conduction of heat	Good conductors.	Most are poor conductors, except diamond (a form of carbon).
Other properties	Strong and bendy.	Solids are brittle.

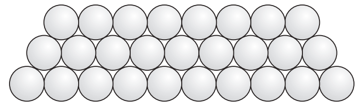
Atom arrangements in metals and non-metals

You can explain the properties in the table by considering:

- how the atoms are arranged
- how the atoms are held together.

Metals

In metals, the atoms are arranged in a huge pattern. Strong forces hold the atoms together. The rows of atoms can slide over each other.



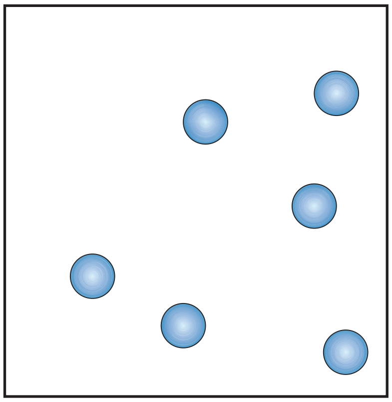
Part of the structure of a typical metal.

Non-metals

Some non-metal elements exist as single atoms. There are weak forces between an atom and its neighbours.

Some non-metal elements exist as **molecules**. A molecule is a group of atoms that are held together by strong forces. There are weak forces between a molecule and its neighbours.

Carbon is different to other non-metals. Its atoms are joined together in a huge structure. The forces between the atoms are very strong.



Helium, neon, argon, krypton, and xenon exist as single atoms.

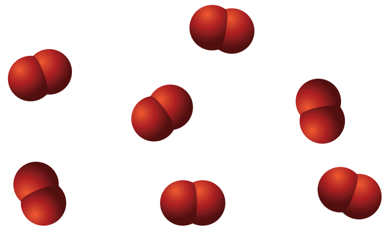
Using atom arrangements to explain properties

Melting and boiling points

Metals have high melting and boiling points. This is because, in their solids, strong forces hold the atoms together. Much energy is needed to overcome these forces to form liquids or gases.

Most non-metals have low melting and boiling points. This is because:

- for elements that exist as molecules, there are weak forces between the molecules
- for elements that exist as single atoms, there are weak forces between the atoms.



An oxygen molecule is made up of two atoms. A very strong force holds the atoms together. There are very weak forces between different molecules.

Strength

Metals are strong. This is because strong forces hold their atoms together.

In the solid state, non-metals are weak. This is because there are weak forces between the molecules.

Bendiness

A thin sheet of a metal is bendy. This is because its rows of atoms can slide over each other.

In the solid state, non-metals are not bendy. They are brittle. For example, if you tap an iodine crystal with a hammer it breaks. This is because there are weak forces between its molecules.

Q

1. Describe three differences between metals and non-metals.
2. Explain why a thin sheet of a metal is bendy, and a thin sheet of a non-metal is not.
3. The melting point of chromium is 1890 °C. The melting point of argon is –189 °C. Suggest a reason for this difference.

!

- Most metals have higher melting and boiling points than non-metals.
- Metals are good conductors of heat and electricity. Non-metals are not.
- Atom arrangements, and forces between atoms, explain metal and non-metal properties.

6.7 What are compounds?

Objectives

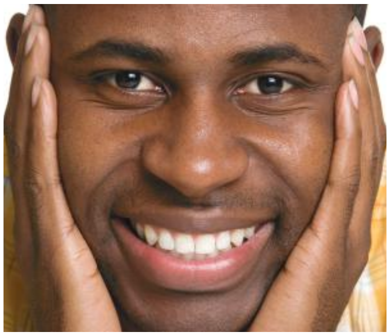
- Understand what a compound is
- Give examples of compounds and state how their properties are different from the properties of their elements

What's in a tooth?

The white part of your teeth is called enamel. It contains atoms of three elements:

- calcium – a shiny metal that fizzes in water.
- phosphorus – a poisonous solid that catches fire easily.
- oxygen – a gas that helps things burn.

So why don't your teeth catch fire? Or poison you? Or fizz when you drink water?



Tooth enamel protects your teeth.

Calcium in water.

Burning phosphorus.

Compounds

The elements in tooth enamel are not just mixed up. Their atoms have joined together to make one substance – calcium phosphate. This substance is different from all the elements that are in it.

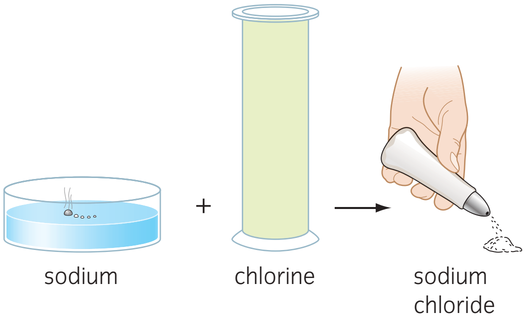
Most substances are not elements on their own. They are made up of atoms of elements joined to atoms of other elements. These substances are **compounds**.

Compound properties

The properties of a compound are different from the properties of the elements in it.

Sodium chloride

Sodium is a shiny metal. It fizzes in water. Chlorine exists as a green, smelly, poisonous gas at 20 °C. These two elements join together to make a compound, sodium chloride. This is the salt you may add to food.

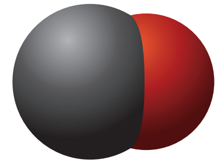


Sodium and chlorine join together to make sodium chloride.

Carbon monoxide

At 20 °C, carbon exists as a solid. Oxygen is a colourless gas – you can't live without it. Joining together 12 g of carbon and 16 g of oxygen makes carbon monoxide. This compound is a deadly poison.

Carbon monoxide exists as molecules. Each molecule consists of one atom of carbon joined to one atom of oxygen.

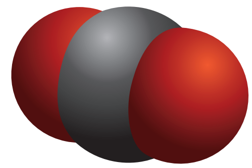


A molecule of carbon monoxide.

Carbon dioxide

You can make another compound from carbon and oxygen. Joining 12 g of carbon with 32 g of oxygen makes carbon dioxide. Carbon monoxide and carbon dioxide have different properties. Carbon dioxide is not poisonous. However, large amounts of carbon dioxide in the air make the Earth hotter.

Carbon dioxide exists as molecules. Each molecule consists of one atom of carbon joined to two atoms of oxygen.



A molecule of carbon dioxide.

Water

Water is a compound. It is made up of the elements hydrogen and oxygen. Each water molecule has one oxygen atom joined to two hydrogen atoms.

A water molecule.

Imagining compounds

Toy bricks can help us imagine compounds.

You can use these bricks to represent carbon atoms…

… and these bricks to represent oxygen atoms.

You can join the bricks like this to show the atoms in carbon monoxide (a compound). Each carbon monoxide molecule is made up of one carbon atom and one oxygen atom.

Q

1 What is a compound?

2 Give one difference between an element and a compound.

3 Use the pictures of the toy bricks to help you answer these questions.

  a How many carbon atoms are in one carbon monoxide molecule?

  b How many oxygen atoms are in one carbon monoxide molecule?

  c What is the total number of atoms in one carbon monoxide molecule?

4 Compare the properties of carbon monoxide to the properties of carbon and oxygen.

!

- A compound is a substance that is made up of atoms of elements joined to atoms of other elements.
- The properties of a compound are different from the properties of its elements.

Enquiry 6.8

Making a compound

Objective

- Understand the stages involved in an enquiry

Developing a question

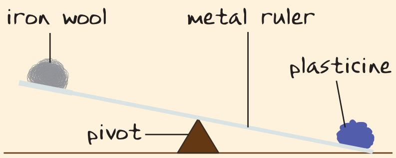
Zac is doing an investigation. He wants to make a compound of iron. He needs some scientific knowledge, so he makes notes from a text book.

If I heat iron wool in air, the iron will join with oxygen. This will make a compound, iron oxide.

Zac decides to heat iron wool in air. He asks a question:

How will I know if a compound is made?

Planning an investigation

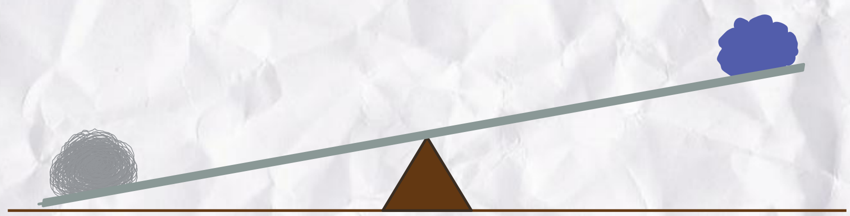


Zac asks his teacher for help. The teacher draws some apparatus that Zac could use.

Zac plans to heat the iron wool with a hot flame. The iron will then react with oxygen from the air. Zac must use a metal ruler because the hot iron wool might set fire to a wooden ruler.

Zac knows that iron atoms have mass. Oxygen atoms have mass too. He makes a prediction.

If I heat iron in air, iron atoms and oxygen atoms will join together. The mass of iron oxide I make will be greater than the mass of iron I start with. So the ruler will tilt like this:



Hazards:

* iron wool – low hazard to health, but can cut skin
* iron wool catches fire easily when in contact with a flame
* when iron wool burns, pieces of burning iron wool fall off
* the metal ruler may get very hot when heated by the hot iron wool

Controlling risks

Zac thinks about the **hazards** of his investigation. A hazard is a possible source of danger. He makes notes from the Internet.

Zac must control the **risks** from these hazards. Risk is the chance of damage or injury from a hazard.

You can plan how to control a risk by thinking about three things:

- time
- distance
- shielding.

Zac makes the decisions below to control risk.

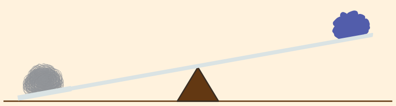
Time – turn off the Bunsen burner as soon as possible, and wait long enough for the equipment to cool before touching it after the experiment.

Distance – stand back from the burning iron wool.

Shielding – keep spare iron wool in a sealed container. Wear eye protection. Wear gloves when handling iron wool.

Considering evidence

Zac heats the iron wool for one minute. The ruler tilts over like this. Zac's prediction was correct.



Zac writes a conclusion for his investigation.

My prediction was correct. The iron wool end of the ruler tilted down.

Zac's teacher asked Zac to improve his conclusion. She told him to use scientific knowledge and understanding to explain his results.

Zac added the sentences below.

When I heated the iron, iron atoms joined with oxygen atoms from the air. This made a compound called iron oxide. The mass of iron oxide was greater than the mass of the iron I started with. So the iron oxide end tilted down.

Doing a calculation

Ava did a similar investigation to Zac. But she also made some measurements.

mass of iron before heating = 4.1 g

mass of iron oxide after heating = 5.6 g

Ava did a calculation to find the mass of oxygen that had joined to the iron.

mass of oxygen = mass of iron oxide – mass of iron

= 5.6 g – 4.1 g

= 1.5 g

Q

1. Explain the difference between a hazard and a risk.
2. List three things to consider when planning how to control risk.
3. Suggest why it is important to use scientific knowledge when writing a conclusion to an investigation.

!

When planning an investigation, use scientific knowledge to:

- develop a question, make a plan, and control risks
- consider evidence.

6.9 Naming compounds and writing formulae

Objectives

- Name compounds
- Write and interpret formulae

Naming compounds

Compounds of a metal and a non-metal

Many compounds are made up of a metal and a non-metal. Follow the rules below to name these compounds.

1. Write the name of the metal.
2. Write the name of the non-metal, but change the end of its name to *-ide*.

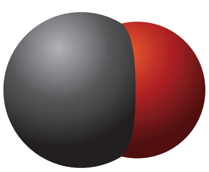
Metal	Non-metal	Name of compound
zinc	oxygen	zinc oxide
sodium	chlorine	sodium chloride
calcium	sulfur	calcium sulfide

Compounds of a metal, a non-metal, and oxygen

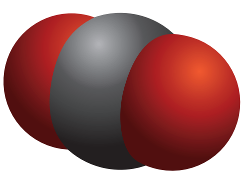
To name a compound made up of a metal, a non-metal, and oxygen, follow the rules below.

1. Write the name of the metal.
2. Write the name of the non-metal, but change the end of its name to *-ate*. The *-ate* shows that the compound contains oxygen.

Elements in compound	Name of compound
copper, sulfur, oxygen	copper sulfate
potassium, nitrogen, oxygen	potassium nitrate
magnesium, carbon, oxygen	magnesium carbonate



Carbon monoxide.



Carbon dioxide.

Compounds containing non-metals only

Some compounds are made up of atoms of non-metals only. To name these compounds, you need to know the numbers of atoms of each element in a molecule of the compound.

This molecule is made up of one carbon atom and one oxygen atom. It is carbon **mon**oxide.

This molecule consists of one carbon atom and two oxygen atoms. Its name is carbon **di**oxide.

Molecule of compound made up of…	Name of compound
1 atom of sulfur and 2 atoms of oxygen	sulfur dioxide
1 atom of sulfur and 3 atoms of oxygen	sulfur trioxide
1 atom of phosphorus and 3 atoms of chlorine	phosphorus trichloride
2 atoms of nitrogen and 4 atoms of oxygen	dinitrogen tetroxide

Writing formulae

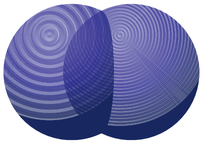
Each element has its own chemical symbol. You can combine chemical symbols to give the **formula** of a compound. A formula shows the number of atoms of each element in a compound. You can also use formulae to represent elements that exist as molecules.

Nitrogen exists as molecules. Each molecule is made up of two atoms. The formula of nitrogen is N_2.

A molecule of carbon dioxide consists of one atom of carbon joined to two atoms of oxygen. Its formula is CO_2.

Follow these rules for numbers in formulae:

- Write each number after (to the right of) its element symbol.
- Write numbers small, and below the line.



A nitrogen molecule.

Name of element or compound	Number of atoms of each element in one molecule ...	Formula
bromine	2 bromine atoms	Br_2
nitrogen monoxide	1 nitrogen atom and 1 oxygen atom	NO
nitrogen dioxide	1 nitrogen atom and 2 oxygen atoms	NO_2
dinitrogen tetroxide	2 nitrogen atoms and 4 oxygen atoms	N_2O_4

Many compounds do not exist as molecules. Their formulae show the ratio of the number of atoms of each element in the compound.

Name of compound	Ratio of number of atoms of each element in the compound	Formula
iron sulfide	1 iron : 1 sulfur	FeS
sodium chloride	1 sodium : 1 chlorine	$NaCl$
copper sulfate	1 copper : 1 sulfur : 4 oxygen	$CuSO_4$
sodium carbonate	2 sodium : 1 carbon : 3 oxygen	Na_2CO_3

Interpreting formulae

Formulae show whether a substance is an element or a compound.

- If a formula includes the chemical symbol of one element only, the substance is an element.
- If a formula includes the chemical symbols of more than one element, the substance is a compound.

Q

1. Name the elements in: copper sulfide, silver bromide, aluminium iodide, iron sulfate, sodium carbonate, silicon dioxide.
2. Name these compounds: KCl, ZnO, SO_2, SO_3, $CuSO_4$
3. Which of these formulae represent compounds: P_4, P_2O_5, N_2, S_8, $CaSO_4$?

!

- The name of a compound shows the elements in it.
- A formula shows the ratio of the number of atoms of each element in the substance.

6.10 Oxides, hydroxides, sulfates, and carbonates

Objectives

- Name some common oxides and hydroxides
- Describe one difference in the properties of metal oxides and non-metal oxides

Oxides

A compound of oxygen with another element is called an **oxide**. Many oxides exist naturally in the Earth's crust. They are often mixed with other oxides in rocks.

Sand is silicon dioxide.

Haematite is iron oxide.

Rubies consist of aluminium oxide with tiny amounts of chromium.

Making oxides

An oxide forms when an element joins with oxygen. For example, if you heat magnesium in air, magnesium oxide quickly forms. The oxygen has come from the air. Heating sulfur in air makes sulfur dioxide.

Some elements join to oxygen without heating. As soon as you cut a piece of aluminium, its surface atoms join with oxygen from the air. Aluminium oxide forms. This oxide is useful – it protects the aluminium underneath it.

Metal or non-metal?

Metal oxides and non-metal oxides have different properties.

Most non-metal oxides are acidic. If you bubble carbon dioxide gas into pure water, a solution forms. Its pH is less than 7. The same happens if you bubble oxides of nitrogen, or oxides of sulfur, into pure water.

Metal oxides are **bases**. This means that they neutralise acids. Some metal oxides, for example sodium oxide, dissolve in water to form alkaline solutions.

Using oxides

The uses of oxides depend on their properties. For example:

- Magnesium oxide has a very high melting point. It is used in furnaces.
- Titanium dioxide is bright white. It is used in paints and toothpastes.

Hydroxides

Compounds made up of a metal, hydrogen, and oxygen, are called **hydroxides**.

- Sodium hydroxide contains atoms of sodium, hydrogen, and oxygen.
- Potassium hydroxide contains atoms of potassium, hydrogen, and oxygen.

Some metal hydroxides dissolve in water to form alkaline solutions.

Formulae of oxides and hydroxides

The tables give the formulae of some oxides and hydroxides.

Name of compound	Ratio of number of atoms of each element in the compound...	Formula
Metal oxides		
magnesium oxide	1 magnesium atom and 1 oxygen atom	MgO
sodium oxide	2 sodium atoms and 1 oxygen atom	Na_2O
aluminium oxide	2 aluminium atoms and 3 oxygen atoms	Al_2O_3

Name of compound	Ratio of number of atoms of each element in the compound...	Formula
Non-metal oxides		
carbon monoxide	1 carbon atom and 1 oxygen atom	CO
carbon dioxide	1 carbon atom and 2 oxygen atoms	CO_2

Name of compound	Ratio of number of atoms of each element in the compound...	Formula
Hydroxides		
sodium hydroxide	1 sodium atom, 1 hydrogen atom and 1 oxygen atom	$NaOH$
potassium hydroxide	1 potassium atom, 1 hydrogen atom and 1 oxygen atom	KOH
calcium hydroxide	1 calcium atom, 2 hydrogen atoms and 2 oxygen atoms	$Ca(OH)_2$

Sulfates

A sulfate is made up of three elements – a metal, sulfur, and oxygen. Its formula is $CuSO_4$. You might have used copper sulfate at school. It exists as blue crystals. Farmers use it to control fungus on fruit crops.

Copper sulfate crystals.

Carbonates

A carbonate is made up of three elements – a metal, carbon, and oxygen. Calcium carbonate exists naturally as limestone and marble. It is a useful building material. Its formula is $CaCO_3$.

Q

1. Name the elements that make up calcium oxide. Would you expect this compound to be acidic or basic?
2. Name the elements that make up lithium hydroxide.
3. Name the elements that make up sodium sulfate.
4. Name the compounds with these formulae: CaO, SiO_2, KOH, $CaCO_3$, Na_2SO_4
5. **Extension:** Give one use of magnesium oxide, and explain how this use depends on its properties.

!

- An oxide is a compound of oxygen and another element.
- A hydroxide is a compound of oxygen, hydrogen, and another element.
- A carbonate is a compound of carbon, oxygen, and another element.
- A sulfate is a compound of sulfur, oxygen, and another element.
- A typical non-metal oxide is acidic; a typical metal oxide is a base.

Enquiry

6.11 Chlorides

Objective

- Plan investigations, present evidence, and consider the evidence

A **chloride** is a compound made up of chlorine and one other element. Examples include sodium chloride and calcium chloride.

Burning sodium in chlorine.

Making sodium chloride

Mrs Mtera makes sodium chloride in the laboratory. First, she fills a gas jar with chlorine gas. Then she heats a small piece of sodium until it melts. She places the sodium in the chlorine gas. The sodium burns with a bright yellow flame. Clouds of white sodium chloride form.

How much salt is in the sea?

There is no need to make sodium chloride. Huge amounts of the salt exist naturally, dissolved in seawater.

Planning an investigation

Emebet wonders how much salt is in the Red Sea. She decides to do an investigation. Her friend, Berekti, says the investigation is impossible – no one could test so much seawater.

Emebet turns her idea it into a question she can test.

What mass of salt is dissolved in 20 cm^3 of water from the Red Sea?

Emebet writes down a plan.

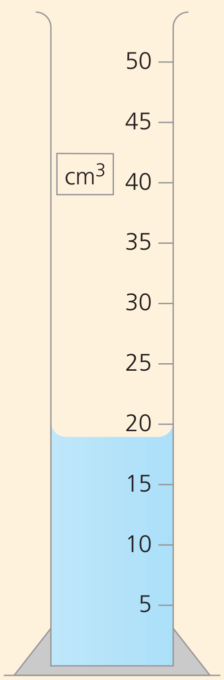
* Measure out 20 cm^3 seawater
* Heat until all the water evaporates
* Find the mass of salt that remains

Obtaining and presenting evidence

Emebet pours seawater into a measuring cylinder. She says its volume is 20 cm^3.

Berekti tells Emebet to add more seawater. The bottom, not the top, of the curved surface of the liquid (the **meniscus**) should be level with the 20 cm^3 mark.

Next, Berekti finds the mass of the empty evaporating basin. It is 25 g. Emebet points out a mistake. The evaporating dish is wet, so its measured mass is too high. Emebet dries the evaporating basin. She places it on the balance again.



Emebet's seawater.

Its mass is 25 g.

Emebet is surprised that the mass values are the same for the dry and wet basins. She realises that she needs a balance that measures smaller differences in mass. She fetches a new balance, and finds the mass of the dry evaporating basin.

mass of evaporating basin is 25.10 g

Berekti points out that they will be making several measurements. It would be better to organise them in a table. Then it will be easier to use the data to do calculations. Berekti's table is below. She has given a unit in the column heading.

	mass (g)
mass of empty evaporating basin	25.10
mass of evaporating basin + salt	25.60
mass of salt	

Emebet and Berekti heat the seawater. The water evaporates. Salt remains. The students measure the mass of the evaporating dish and salt.

Considering evidence

They students calculate the mass of salt:

mass of salt = (mass of evaporating basin + salt) – (mass of evaporating basin)
= 25.60 g – 25.10 g
= 0.50 g

The students have set out their calculation clearly. This makes it easy to check, or do a similar calculation later.

The teacher suggests that Emebet and Berekti repeat their investigation three more times. They can then calculate an average value for the mass of salt in 20 cm^3 of seawater. This result is more accurate than just one result.

To finish the investigation, Emebet uses a secondary source to help estimate the volume of water in the Red Sea. She then uses this value, and her investigation data, to estimate the mass of salt in the Red Sea.

Q

1. Name the chloride that is made up of potassium and chlorine.
2. Explain why Emebet and Berekti write their results in a table.
3. Explain why repeating an investigation several times can improve the accuracy of data.
4. Suggest why Emebet and Berekti are unlikely to get identical results when they repeat their investigation.

!

Doing and investigation involves:

- devising a question
- planning
- obtaining, presenting, and considering evidence

6.12 Mixtures

Objective

- Understand the differences between elements, mixtures, and compounds

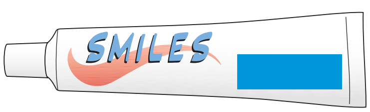
Introducing mixtures

Prita spills water in the salt. Prema finds a stone in her rice. Priyam crunches sand in her salad.

Salt and water, stones and rice, and sand and salad are all **mixtures**. The substances in mixtures are not joined to each other. They are just mixed up.

Often, it is easy to separate the substances in a mixture. Prema could pick stones out of her rice. Priyam could wash sand off her salad. Prita could evaporate water from her salt.

A mixture of elements.



A mixture of compounds.

Orange juice is a mixture of compounds.

Different mixtures

Mixtures can contain elements, compounds, or both.

Salim has two sorts of nails – iron and copper. He keeps them in a jar. Iron and copper are both elements. So the jar contains a mixture of elements.

The label shows the ingredients in toothpaste. The ingredients are all compounds. So toothpaste is a mixture of compounds.

Air – an important mixture

Air is a mixture of substances, including:

- elements – for example nitrogen (N_2), oxygen (O_2), and argon (Ar)
- compounds – for example carbon dioxide (CO_2).

How are elements, mixtures, and compounds different?

Ricardo collects 7 g of iron powder and 4 g of sulfur powder. Iron is an element. It is made up of one type of atom. It cannot be split into anything simpler. Ricardo holds a magnet near the iron powder. It jumps onto the magnet.

Sulfur is also an element. It is made up of one type of atom. Its atoms are different from iron atoms.

Iron filings.

Sulfur powder.

Ricardo mixes his iron and sulfur. He can see the individual elements. He can separate them with his magnet. Ricardo has a mixture. Its properties are similar to those of the elements in it. The elements have not joined together, so is easy to separate them.

The amounts of iron and sulfur in the mixture are not important. Whatever the amounts of iron and sulfur, it is still a mixture.

Ricardo heats his mixture. The two elements join together. A compound, iron sulfide, has formed. Ricardo cannot get iron out of the compound with his magnet. The compound looks different from the elements it is made from. Its properties are different from its elements.

The amounts of elements in a compound are important. Iron sulfide always contains iron and sulfur in the ratio of 7:4 by mass.

A mixture of iron and sulfur.

Iron sulfide.

The table summarises the differences between mixtures and compounds.

	Compound	**Mixture**
Number of types of atoms	More than one, joined together.	More than one.
Can it be separated into simpler substances?	Not easily – chemical reaction needed.	Yes
Properties	Different properties from its elements.	Same properties as substances in it.
Amounts	Amounts of its elements are always in the same ratio.	Amounts of substances can change.

Q

1 What is a mixture?

2 Describe three differences between a mixture and a compound.

3 List five mixtures and five compounds.

4 A mixture includes substances with these formulae: CO_2, N_2, SO_3, O_2. Is it a mixture of elements, a mixture of compounds, or a mixture of elements and compounds?

!

- The substances in a mixture are not joined up, and can be separated.
- A mixture has similar properties to the substances in it.

Enquiry
6.13 Separating mixtures – filtering and decanting

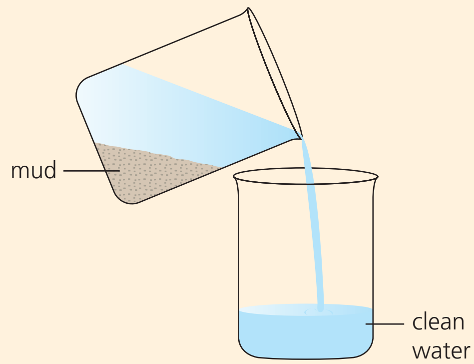
Objectives

- Describe how to separate mixtures by decanting and filtering
- Understand how to plan an investigation

Decanting

Tabia collects water from a pond. The water is muddy. She takes it home and leaves it in the bucket. The mud settles to the bottom. Later, Tabia carefully pours the water into a storage container. This is **decanting**. The mud remains in the bucket.

Tabia used decanting to separate a mixture of a liquid and a solid. You can also use decanting to separate liquids, if one liquid floats on the other.



Decanting involves carefully pouring off a liquid from a mixture.

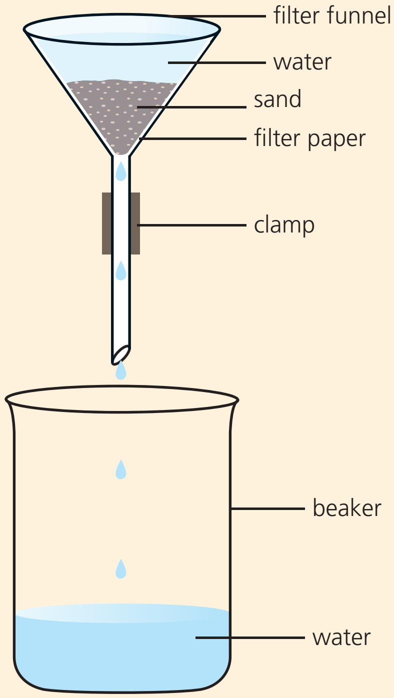
Filtering

At school, Wira has a mixture of sand and water. Sand does not dissolve in water. It is insoluble. Wira wants to separate the sand from the water. He pours the mixture onto a piece of filter paper. Sand remains in the filter paper. Water passes through tiny holes in the paper.

Wira has **filtered** the sandy water. He has used **filtration** to separate an insoluble solid from a liquid.

Anvita's teacher gives her a mixture of salt and sand. He tells her to separate the sand and salt. Anvita adds hot water to the mixture, and stirs. The salt dissolves in the water.

Next, Anvita filters the mixture. Sand remains in the filter paper. The salt solution passes through the paper. Anvita removes the sand from the paper, and keeps it to show her teacher. Turn over to find out how to separate solid salt from salt solution.



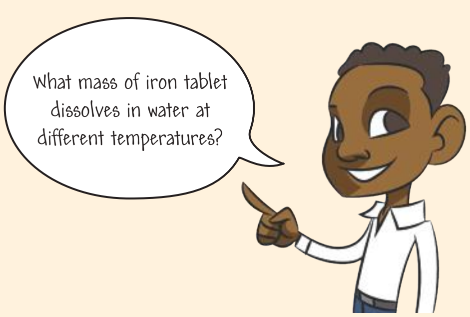
Filtration separates an insoluble solid from a liquid.

Planning an investigation

Turning ideas into a form that can be tested

Jamal's mum takes iron tablets. Iron tablets contain compounds that contain iron. Jamal plans a project about iron tablets. He wants to investigate their solubility in water of different temperatures.

First, Jamal thinks of a question to test.



Considering variables

Jamal lists all the possible variables. He decides which to change, control, and measure.

Temperature – change this variable
Mass of iron tablet that dissolves – measure this variable
How fast I stir – control this variable
Volume of water – control this variable

Jamal needs to decide what volume of water to use. He tries dissolving a tablet in 10 cm^3 of water, then in 100 cm^3 of water, and lastly in 1000 cm^3 of water at room temperature. He chooses to use 100 cm^3 of water for his investigation. With this volume, some – but not all – of the tablet dissolves. This means that, in this volume of water, it is possible that different masses of tablet will dissolve at different temperatures.

Planning what to do

Jamal writes a plan. He decides to use filtering to separate the solution from the solid that does not dissolve.

1. Measure out 50 cm^3 water. Find its temperature.
2. Find the mass of a tablet.
3. Add the tablet to the water. Stir.
4. Filter the mixture.
5. Keep the solid in the filter paper. When it dries, find its mass.
6. Calculate the mass of iron tablet that dissolved.
7. Repeat at 4 different temperatures.

Making predictions and obtaining evidence

Jamal makes a prediction. He knows that, for many substances, the higher the temperature, the more dissolves. He uses this scientific knowledge to predict that the same will be true in his investigation.

Jamal carries out his investigation. He finds that his prediction is correct.

Q

1. Draw and label two diagrams to show how to separate mud from water by decanting and by filtering.
2. Franco has a mixture of olive oil and water. Suggest how to separate the two liquids.
3. Zumila wants to use filtration to separate salt from salty water. Explain why this will not work.

!

- Decanting separates a liquid from a solid, or liquids of different densities.
- Filtering separates an insoluble solid from a liquid or solution.

6.14 Separating mixtures – evaporation and distillation

Objective

- Understand how evaporation and distillation separate liquids and solids from solutions

Use pages 120–3 to review what you learned about Separating mixtures *at Primary level. Think about how the rest of this chapter helps you understand how mixtures are separated.*

Evaporation

Copper sulfate crystals

Savit is making copper sulfate crystals. He has made copper sulfate solution, which is a mixture of copper sulfate and water. Now he needs to remove water from the mixture.

Savit decides to remove the water by **evaporation**. First, he heats the solution over a Bunsen burner. The water in the solution boils. Some of the water escapes from the solution as bubbles of steam. All the copper sulfate remains in the evaporating dish.

When about half the liquid water has changed state to become steam, Savit stops heating. He leaves the evaporating dish and its contents in a warm, dry room. Water evaporates from the solution. After a few days, all the water has evaporated. Copper sulfate crystals remain.

Heating copper sulfate solution.

Copper sulfate solution.

All the water has evaporated from the solution. Copper sulfate crystals remain.

Sodium chloride

People extract huge amounts of salt from seawater. Seawater is a mixture of water and sodium chloride (salt).

Seawater flows into large shallow ponds, called salt pans. Pure water evaporates from the seawater – the Sun provides energy for this process. Solid salt remains in the ponds.

Salt pans near Puducherry, India.

Lithium compounds

Every year, companies make more and more electric cars. The cars are powered by lithium-containing batteries. Huge amounts of lithium will be needed.

Up to half of the world's lithium is found in Bolivia. Lithium compounds are dissolved in water under an enormous salt desert.

The Bolivian government plans to bring lithium compound solution to the surface. Then energy from the Sun will make water evaporate. Solid lithium compounds will remain. The process works because the water and the lithium compounds are not joined to each other. They are just mixed up.

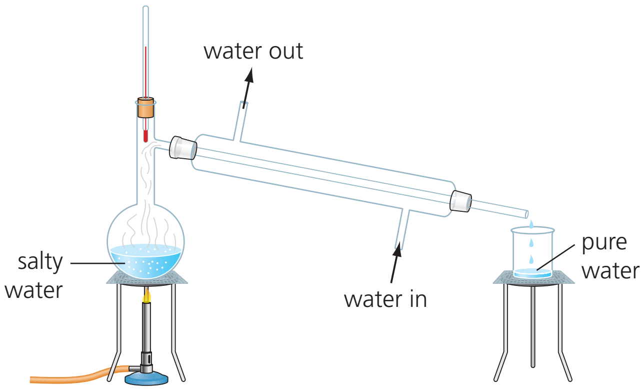
Salar de Uyuni, Bolivia's salt desert.

Distillation

It rains very little in Saudi Arabia. There are no permanent rivers or lakes, so about half the country's drinking water comes from the sea. But you can't drink seawater.

Huge plants like this one supply water to Saudi Arabian homes. The plants take in seawater. They separate pure water from the compounds that are dissolved in it. They use a process called multistage flash distillation.

This plant separates pure water from seawater.



Simple distillation apparatus.

In the laboratory, you can use the apparatus above to separate pure water from seawater by **distillation**. The salty water boils. Some of the liquid water evaporates, forming steam. Steam travels through the condenser and cools down. It condenses to liquid water. The liquid water goes into the beaker. The compounds that were dissolved in the seawater remain in the flask.

Q

1. Name two important substances that can be obtained by evaporation.
2. Kish has some salt solution. He wants to separate salt from the solution. Should he use distillation or evaporation? Explain your decision.
3. Describe how to separate pure water from a solution of ink in the laboratory. Include a labelled drawing of the apparatus.

!

- Evaporation removes the solvent from a solution. The solute remains.
- Distillation involves evaporating and condensing the solvent from a solution.

Extension 6.15

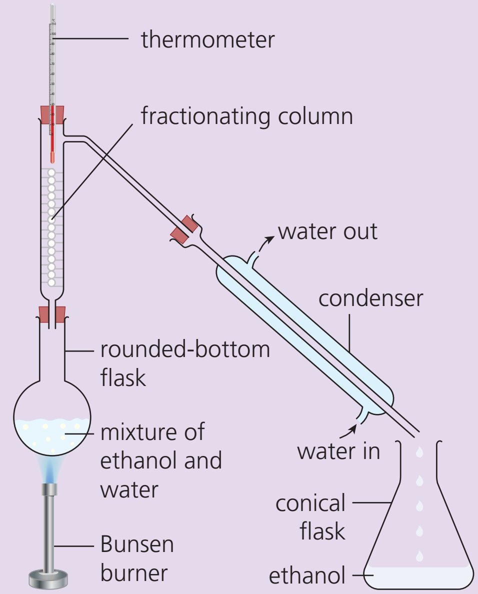
Separating mixtures – fractional distillation

Objective

- Explain how fractional distillation separates mixtures of liquids with different boiling points

Distillation

Simple distillation can be used to separate pure water from salty water (see page 121). The process also works for other solutions. You can use it to separate pure water from copper sulfate solution, for example.



Laboratory apparatus for fractional distillation.

Fractional distillation

Ethanol and water

Fractional distillation separates mixtures of liquids. It only works if the liquids have different boiling points.

Mr Hassan is a science teacher. He has a mixture of ethanol and water. He sets up the apparatus opposite. He heats the flask gently.

Substance	Boiling point (°C)
ethanol	78
water	100

As the mixture gets hotter, both liquids evaporate. Vapours form. At first, both vapours condense when they reach the cooler fractionating column.

When the fractionating column reaches 78 °C, ethanol vapour does not condense. It enters the condenser. Here, ethanol vapour cools and condenses. Liquid ethanol drips into the beaker. Mr Hassan continues to heat gently, so that the temperature stays at 78 °C.

When all the ethanol has evaporated, Mr Hassan removes the beaker of liquid ethanol. He heats more strongly. The temperature of the fractionating column gets higher.

When the fractionating column reaches 100 °C, water vapour no longer condenses in it. Instead, water vapour enters the condenser. There, it condenses, and drips into the beaker. Mr Hassan has separated his mixture of liquids.

Crude oil

Diesel is a mixture of compounds. Most compounds in diesel are made up of atoms of hydrogen and carbon only. They are called hydrocarbons. Most molecules in diesel contain between 14 and 19 carbon atoms.

Petrol (also called gasoline, or gas) is also a mixture of hydrocarbons, but its molecules are smaller. Most molecules in petrol contain between five and ten carbon atoms.


Diesel is used as a fuel in lorries, buses, and some cars.

Diesel and petrol are separated from crude oil. Crude oil is a mixture of hundreds of hydrocarbons.

Crude oil is heated to more than 450 °C. Its compounds become gases. The gases enter a fractionating column. They move upwards, getting cooler all the time.

As the gases cool, they condense. Because they have different boiling points, they condense at different temperatures. The compounds that make up diesel have high boiling points. They do not need to cool much to turn back into liquids. They condense near the bottom of the column, where the temperature is about 260 °C. The liquid is drained off.

Higher up the column, the temperature is lower. Here, petrol compounds condense.

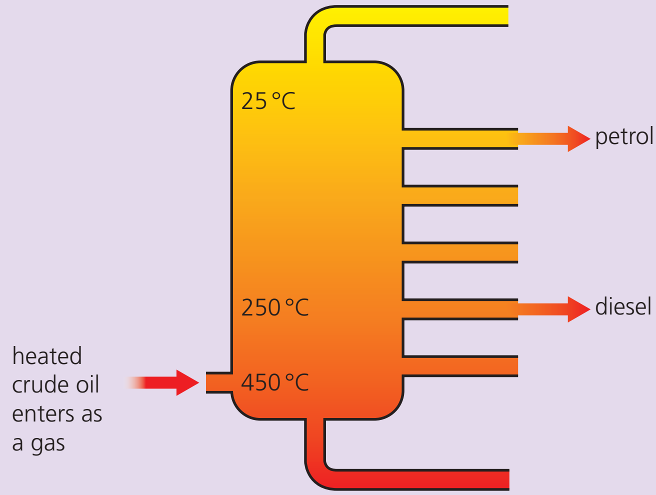
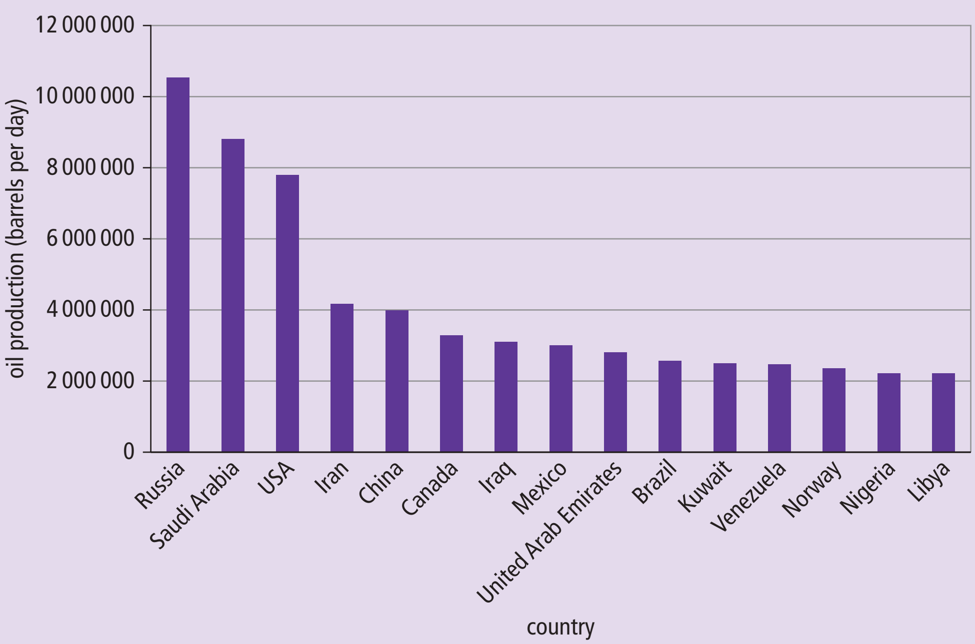


Diagram of an industrial fractionating column.

Considering evidence – interpreting data from secondary sources

Crude oil is hugely important. Most crude oil is used for fuels. But we also use it to make plastics, paints, and medicines.

The bar chart shows the amounts of crude oil produced by the 15 top oil producing countries.



Crude oil production.

This oil refinery in Nigeria uses fractional distillation to separate useful products from crude oil.

Q

1. What type of mixture can be separated by fractional distillation?
2. Explain why, in fractional distillation, the liquid with the lower boiling point is collected first.
3. Miss Chuma has a mixture of hexane and heptane. The boiling point of hexane is 69 °C. The boiling point of heptane is 98 °C. Which liquid will she collect first during fractional distillation of the mixture?
4. Name the top three crude-oil producing countries shown in the bar chart.

!

- Fractional distillation separates liquids with different boiling points.

6.16 Separating mixtures – chromatography

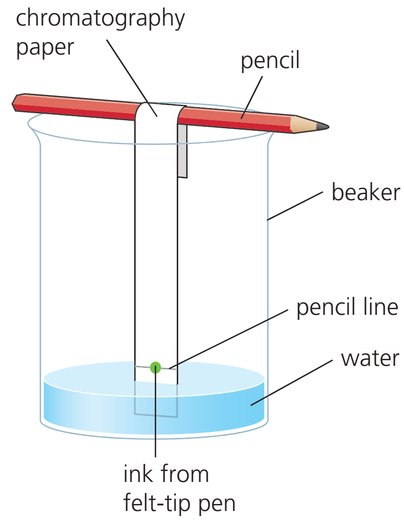
Objectives

- Understand how chromatography separates mixtures
- Give examples of uses of chromatography

Chromatogram from a green felt-tip pen.

What is chromatography?

You can use **chromatography** to separate compounds from mixtures of compounds. Chromatography works if all the substances in the mixture dissolve in one solvent.



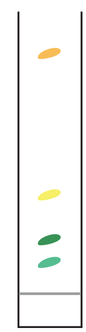
Chromatography apparatus.

Chromatography of ink

Mita sets up the apparatus opposite. The water moves up the paper. It takes the dyes in the ink with it. Different dyes move at different speeds, so they separate. A **chromatogram** is produced.

In the chromatogram, the blue dye goes further up the paper. This might be because the blue dye dissolves better in the solvent. Or it might be because the yellow dye sticks more strongly to the paper. You cannot tell just by looking at the chromatogram.

Chromatography of spinach



Rashid grinds up a spinach leaf. He puts a spot of spinach juice near the bottom of a piece of chromatography paper. He stands the paper in a solvent. He obtains the chromatogram shown opposite. It shows the pigments (colours) in spinach. Each pigment is a different nutrient.

Using chromatography

There are several chromatography techniques. They all separate mixtures of compounds. Scientists use them to identify compounds in mixtures, and to measure the amounts of compounds in mixtures. For example:

- In some countries, police forces use chromatography to measure the alcohol in a driver's blood. This shows whether the person has had too much alcohol to drive safely.
- Detectives have used chromatography to look for explosives on the body hair of bomber suspects.
- Scientists use chromatography to identify nutrients in foods.

Ideas and evidence – using chromatography

Developing empirical questions

In Africa and southern Asia, up to 100 000 children go blind each year. A major cause of blindness is lack of vitamin A.

Many people in Africa and southern Asia eat a diet rich in cassava. Nigerian scientist Steve Adewusi and Australian Howard Bradbury wondered if different types of cassava contain different amounts of vitamin A. Would switching to vitamin-A rich cassava prevent childhood blindness?

The scientists developed an empirical question:

How much vitamin A is in the roots and leaves of different types of cassava?

Cassava roots are important foods. The leaves of the cassava plant are also a common food in Africa and Asia.

Collecting evidence

The scientists did experiments to collect evidence to help answer their question. They used chromatography to measure the amounts of vitamin A in yellow cassava roots and in white cassava roots. They also measured the amounts of vitamin A in dark green and light green cassava leaves.

The scientists also collected data from a secondary source, the World Health Organisation. The data included the recommended daily vitamin A intake for children.

Yellow cassava roots.

White cassava roots.

Developing explanations

The scientists studied their results. They concluded that yellow cassava roots are richer in vitamin A than white roots. Dark green leaves are richer in vitamin A than light green leaves.

The scientists thought about their evidence. They calculated the mass of cassava that provides the recommended intake of vitamin A. They worked out that eating yellow cassava root, and cassava leaves, can provide enough vitamin A. White roots alone cannot.

The scientists made a recommendation. To prevent childhood blindness, children should eat yellow cassava, not white.

Q

1. Which of these mixtures can be separated by chromatography: sand and salt; coloured compounds in leaves; dyes in ink; water and salt. Give reasons for your decisions.
2. Explain why, in chromatography, some substances travel further up the paper than others.
3. Describe one use of chromatography.

!

- Chromatography can separate mixtures of substances that are soluble in the same solvent.

Extension 6.17

Separating metals from their ores

Objectives

- Describe how to separate metals from ores
- Calculate the mass of metal obtained from an ore sample

Substance	Density (g/cm^3)
gold	19.3
quartz (the main substance in sand)	2.7

Separating gold from sand

Gold exists naturally as an element on its own. It is sometimes found mixed with sand on riverbeds. Gold is separated from its mixture by panning.

Panning works because the substances in the mixture have different densities.

Gold falls to the bottom of the pan. Sand mixes with the water and, on shaking, escapes over the edge of the pan.

Panning for gold.

Extracting tin from its ore

Most metals do not exist naturally as elements on their own. They are found joined to other elements, in compounds. These compounds are mixed with other compounds in rocks. Rocks from which metals are extracted are called **ores**.

Tin ore.

It is not easy to extract a metal from its ore. There are often many stages. Much energy is needed for some of these stages.

Tin exists naturally as tin oxide, SnO_2. The tin oxide is mixed with other compounds in tin ore. In China, South America, and Australia, most tin ore is deep underground. In Indonesia most tin ore is in riverbeds, mixed with sand and mud.

Tin is extracted from riverbed ores that contain 0.015% or more tin by mass. First, tin oxide is separated from the substances it is mixed with:

- filtration separates tin oxide from big pieces of unwanted material
- gravity separates tin oxide from sand and mud. This works because tin oxide has a higher density than sand and mud.

The filtration and gravity produce almost pure tin oxide. It contains more than 70% tin by mass.

The tin oxide is placed in a furnace with carbon. The mixture is heated to 1400 °C. Carbon removes oxygen from the tin oxide. Tin metal remains.

The tin metal is not pure. There are small amounts of other elements mixed with it. The table lists some of these elements, and their melting points.

Element	Melting point (°C)
tin	232
iron	1535
copper	1083

The mixture is separated by heating. Tin melts at the lowest temperature. It is poured off. The other elements are left behind.

Considering evidence and approach

Ore calculations

A miner has some tin ore. Its tin content is 0.015%. The miner works out the mass of tin in different masses of ore.

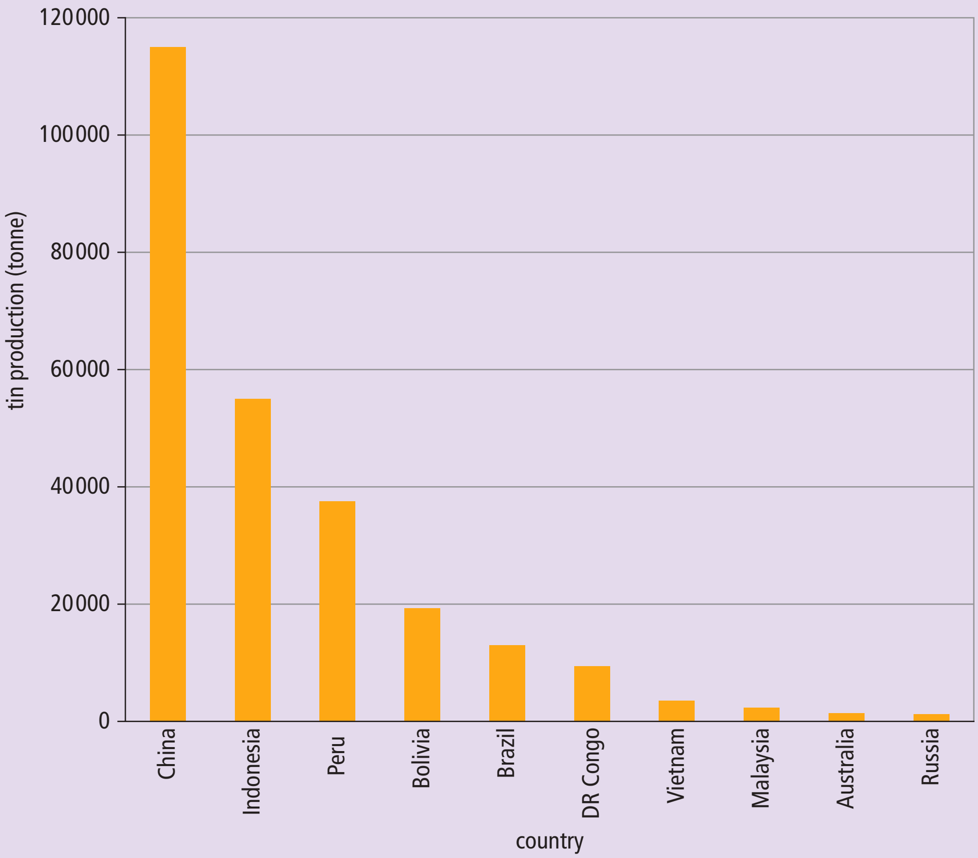
Mass of tin in 100 g of ore = 0.015 g

The mass of tin in 1000 g (1 kg) of ore = 0.015 g × 10
= 0.15 g

The mass of tin in 1000 kg (1 tonne) of ore = 0.15 g × 1000
= 150 g

Interpreting data from secondary sources

The bar chart shows the amounts of tin produced by the top ten tin producing countries.



Q

1. Explain how panning separates a dense metal, or metal-containing compound, from the less dense substances it is mixed with.
2. Name two processes used to separate tin ore from the other substances it is mixed with.
3. Describe how tin metal is extracted from its compound.
4. Calculate the mass of tin that can be extracted from 100 kg of tin ore that contains 1% tin by mass. Calculate the mass of waste produced.
5. Name one country that produce more tin than Indonesia.

!

- Panning separates a dense metal, or metal-containing compound, from the less dense substances it is mixed with.
- Tin is separated from tin oxide by heating with carbon.
- Tin is separated from metal impurities by melting.

Extension

6.18 What are you made of?

Objective

- Name the main elements in living things

Inside Asim

Asim has a mass of 50 kg. His body contains:

- enough hydrogen to fill his classroom
- enough oxygen to fill a room in his house
- enough nitrogen to fill his school bag 85 times
- and enough carbon to make a huge number of pencils.

Asim's body also contains 0.5 kg of phosphorus and small amounts of many other elements. The elements in Asim's body are not just mixed up. They are joined together in hundreds of different compounds.

Asim's blood is a mixture of compounds, including water. Water is a compound of hydrogen and oxygen.

Asim's nails are mainly keratin. Keratin is a compound. It is made of atoms of carbon, hydrogen, oxygen, and nitrogen. There are also atoms of sulfur, which makes keratin hard and rigid.

All Asim's body tissues and organs – including his skin, bones, brain, and heart – are compounds made mainly of carbon, hydrogen, oxygen, and nitrogen.

Body chemicals – where do they come from?

Everyone needs the element oxygen. The air you breathe contains 21% oxygen mixed with other gases. Your lungs separate oxygen from these gases.

Everyone needs water, too. It comes from our food and drink.

As well as water and oxygen, you need proteins, fats, and carbohydrates. These are all compounds. They are in your food.

Other important chemicals

To keep healthy, your body needs small amounts of **vitamins**. Vitamins are compounds made up mainly of the elements carbon, hydrogen, and oxygen.

You also need small amounts of other elements, such as iron and calcium. But it's no use swallowing iron nails or lumps of calcium metal. You need compounds that contain these elements, called **minerals**.

Mineral deficiency

If you do not take in enough of any mineral, you may suffer symptoms of mineral deficiency.

Mineral	Symptoms of deficiency
iron	tiredness, lack of energy, shortness of breath
calcium	weak bones and frequent fractures
zinc	reduced growth in children, problems with senses and memory
iodine	swelling of thyroid gland in neck, tiredness, brain damage

Iodine deficiency

In the 1980s, about 25% of people in Tanzania had iodine deficiency disorders. The government told salt makers to add iodine to all salt sold in Tanzania.

The government wanted to know if its policy had worked. In 2004, scientists investigated two questions:

- What percentage of households use salt with added iodine?
- Did fewer people suffer from iodine deficiency in 2004 than in the 1980s?

The scientists gathered evidence. They tested salt samples from 156 000 households. Iodine had been added to more than 80% of the salt samples.

The scientists tested 166 000 children for iodine deficiency symptoms. The percentage of children with iodine deficiency had decreased from 25% in the 1980s to 7% in 2004.

The scientists studied their evidence and made conclusions. In most areas, the greater the number of people eating iodized salt, the smaller the number of people with iodine-deficiency. This is an **inverse correlation**.

The scientists want the government to make sure that iodine is added to all salt in future. They now want to investigate iodine deficiency in pregnant women.

This woman has not had enough iodine in her diet.

Q

1. Name the four elements that make up most of the mass of your body.
2. What is a mineral?
3. Describe what may happen if you do not take in enough iron.
4. Give the symptoms of calcium deficiency, iodine deficiency, and zinc deficiency.

!

- Our bodies are made up of compounds containing mainly the elements carbon, hydrogen, and oxygen.
- Our diet should include proteins, carbohydrates, fats, vitamins, and minerals.

Review 6.19

1 Copy and complete the table.

Element name	Chemical symbol
	B
	Be
silicon	
sodium	
sulfur	
chlorine	
fluorine	
potassium	

[8]

2 Copy and complete the table to show whether each substance is an element or a compound.

Name of substance	Formula	Element or compound?
nitrogen	N_2	
carbon dioxide	CO_2	
sulfur	S_8	
argon	Ar	
magnesium oxide	MgO	
copper sulfate	$CuSO_4$	

[6]

3 The table gives data for four elements. Each element is represented by a number.

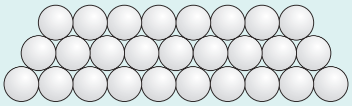
Element	Melting point (°C)	Does it conduct electricity?	Is its oxide acidic or basic?
1	113	no	acidic
2	850	yes	basic
3	–210	no	acidic
4	1063	yes	does not form an oxide

a Give the numbers of the elements in the table which are metals. [1]

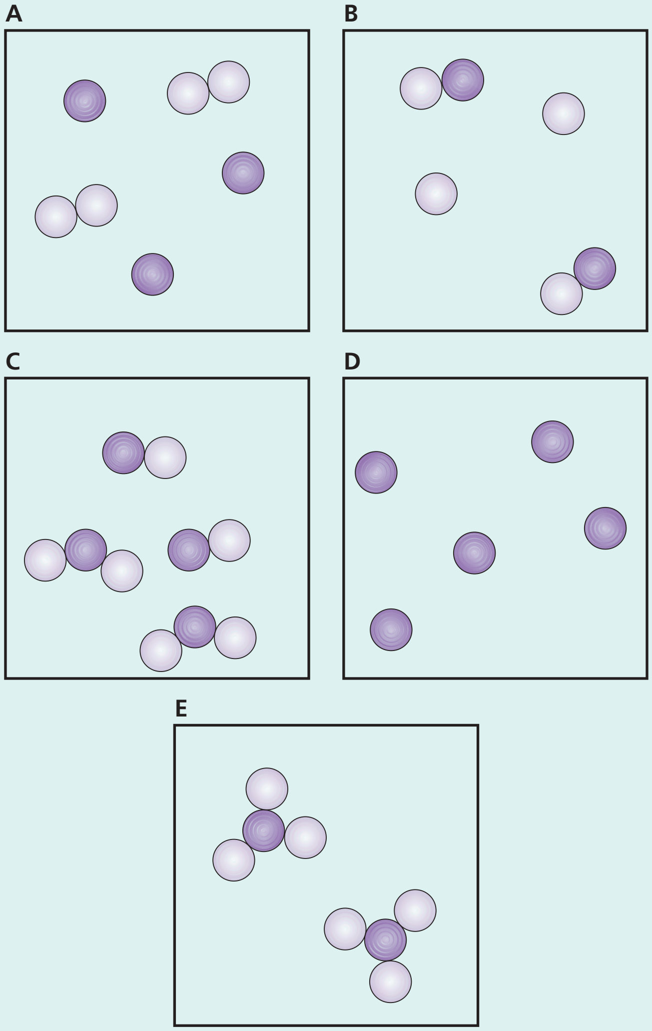
b Give the numbers of the elements in the table which are likely to be shiny. [1]

c Give the numbers of the elements in the table which are likely to be malleable. [1]

4 The diagram shows the atoms in a thin sheet of metal. Use the diagram to help you explain why a thin sheet of metal is easy to bend. [2]



5 The diagrams show some particles of gases.



a Write the letters of the diagrams that show gases that exist as single atoms. [3]

b Write the letters of the diagrams that show gases that exist as molecules. [4]

c Write the letter of the diagram that shows a mixture of elements. [1]

d Write the letter of the diagram that shows a mixture of compounds. [1]

e Write the letter of the diagram that shows a mixture of an element and a compound. [1]

f Write the letter of the diagram that shows a single element. [1]

g Write the letter of the diagram that shows a single compound. [1]

6 Copy and complete the sentences below. Use these phrases. You can use each phrase once, more than once, or not at all.

one **more than one** **different from**
the same as **can vary** **are always the same**

A compound is made up of __________ type of atom. Its properties are __________ the elements that are in it. The amounts of each element in a certain compound __________.

A mixture contains __________ substance. Its properties are __________ the substances that are in it. The amounts of the substances in a mixture __________. [6]

7 Copy and complete the table to show the names of the elements that are in each compound. [5]

Compound	Elements in compound
calcium oxide	
sodium chloride	
potassium hydroxide	
iron sulfate	
magnesium carbonate	

8 Write the names of the elements represented by the formulae below.

a $MgSO_4$ [1]

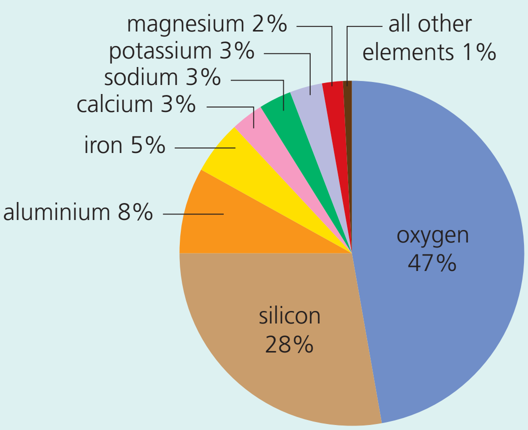
b NaCl [1]

c $CaCO_3$ [1]

d BeO [1]

e KOH [1]

9 The pie chart shows the percentage by mass of the different elements that make up the substances in the Earth's crust.



a Write down the names and symbols of 6 metal elements in the Earth's crust. [6]

b Name the metal element in the Earth's crust which is present in the greatest amount. [1]

c Name the two elements which together make up 75% of the mass of the Earth's crust. [1]

d Oxygen exists in the Earth's crust not as an element, but in compounds. Give one difference between an element and a compound. [1]

10 Sahira wants to investigate mass changes when she burns metals in air.

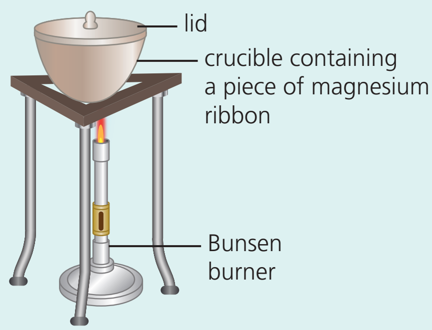
a Sahira writes down two possible questions to investigate.

– how do the masses of all metals change when they burn?

– what is the mass change of magnesium when it burns?

Sahira's teacher tells her to investigate the second question above. Suggest why. [1]

b Sahira draws the apparatus for investigating the mass change of magnesium when it burns to make magnesium oxide.



Sahira must open the lid a few times as she heats. Suggest why. [1]

c Sahira writes down some hazards of the investigation. Complete the table to show how she can control the risks from these hazards.

Hazard	How to control risks from hazard
magnesium is highly flammable	
burning magnesium has a very bright flame	

d Sahira writes down her results.

Mass of crucible + lid = 32.00 g

Mass of magnesium = 0.24 g

Mass of crucible + lid + magnesium oxide = 32.40 g

i Calculate the mass of magnesium oxide made. [2]

ii Calculate the mass of oxygen that joined with the magnesium in Sahira's experiment. [2]

e Sahira writes the conclusion below.

In my investigation, the mass increased.

Add a scientific explanation to improve Sahira's conclusion. [2]

7.1 Chemical reactions

Objectives

- Know what chemical reactions are
- Know how to recognise chemical reactions

What is a chemical reaction?

What links the pictures below?

The pictures show places where chemical reactions happen. In fact, chemical reactions happen everywhere, all the time, even inside you!

Scientists study chemical reactions in laboratories, too. They use them to develop medicines, fuels, and materials.

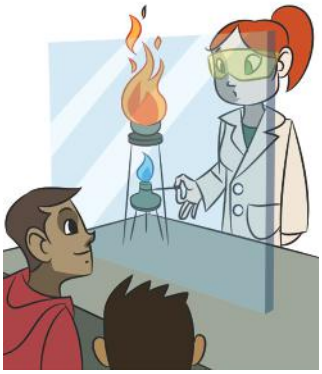
All chemical reactions:

- create new substances – the substances you end up with are different from the ones you started with.
- are not reversible – at the end of the reaction, you cannot easily get back the substances you started with.

The signs of a chemical reaction

You do an experiment in the lab. How do you know if it was a chemical reaction? There are many clues to look out for. You might:

- see huge flames … or tiny sparks



- notice a sweet smell … or a foul stink

- feel the chemicals getting hotter … or colder

- hear a loud bang … or gentle fizzing.

By the end of the reaction, what you see probably looks very different to what you started with.

Combustion reactions

Magnesium

Farah heats a piece of magnesium metal in a Bunsen burner flame. She looks away quickly and shields her eyes. Suddenly, there is a bright white flame.

The flame soon goes out. White ash remains.

Farah explains her observations. She saw a chemical reaction. In the reaction, magnesium reacted with oxygen from the air. The white ash is magnesium oxide. It was made in the chemical reaction.

The substances that react in a chemical reaction are **reactants**. The substances that are made are **products**.

The reaction of magnesium with oxygen is an example of a **burning**, or **combustion**, reaction. Any reaction in which a substance reacts quickly with oxygen, and gives out heat and light, is a combustion reaction.

Halim does a similar experiment. He finds the mass of a piece of magnesium, and heats it in a crucible. He lifts the lid three times during the reaction so that air can get in.

Halim works out the mass of the product. It is greater than the mass of the magnesium he started with. This is evidence that magnesium has joined with another substance – oxygen, from the air.

The combustion reaction of magnesium.

Heating magnesium in a crucible.

Mass of crucible + lid = 30.00 g

Mass of magnesium ribbon = 0.24 g

Mass of crucible + lid + product = 30.40 g

Mass of product = (mass of crucible + lid + product) – (mass of crucible + lid)

= 0.40 g

Carbon

Chan heats a piece of carbon in the air. It glows red. Its mass decreases.

Chan explains her results. A combustion reaction has happened. Carbon has reacted with oxygen from the air to make carbon dioxide.

The reactants are carbon and oxygen. The product is carbon dioxide. Carbon dioxide is a colourless gas that escapes into the atmosphere as it is produced.

Q

1. Give two characteristics of chemical reactions.
2. List three signs of chemical reactions.
3. Phizz heats some iron in air. It reacts with oxygen to make iron oxide. Name the reactants and products in this reaction.
4. Explain why, if you heat carbon in air, its mass decreases.
5. Kezi heats 0.12 g of magnesium in air. It burns to make 0.20 g of magnesium oxide. What mass of oxygen has joined to the magnesium in this reaction?

!

- Chemical reactions create new substances.
- Chemical reactions are not reversible.

7.2 Writing word equations

Objective

- Write word equations to represent chemical reactions

Word equations

You can use **word equations** to show reactions simply. This word equation shows the combustion reaction of magnesium:

magnesium + oxygen → magnesium oxide

A word equation shows:

- reactants (starting materials) on the left
- products (what is made in the reaction) on the right.

The arrow means *react to make*. In a chemical equation, the reactants and products are different from each other. So the arrow in a chemical equation has a different meaning to the equals sign (=) in a maths equation.

The word equation below shows the combustion reaction of carbon in plenty of air to make carbon dioxide:

carbon + oxygen → carbon dioxide

Acid reactions

Combustion reactions are not the only type of reaction. There are many others. This section is about acid reactions.

Acids and alkali

Sam adds sodium hydroxide to hydrochloric acid. The alkali reacts with the acid. A **neutralisation** reaction has happened.

The products of the reaction are sodium chloride and water. This word equation shows the reaction:

hydrochloric acid + sodium hydroxide → sodium chloride + water

Sodium chloride is the salt you can add to food.

Acids with metal oxides

You can also neutralise acids with metal oxides. The equation shows an example.

sulfuric acid + copper oxide → copper sulfate + water

Copper sulfate is a **salt**. But it is not the salt in food. Scientists say that a salt is a compound made when a metal replaces hydrogen in an acid.

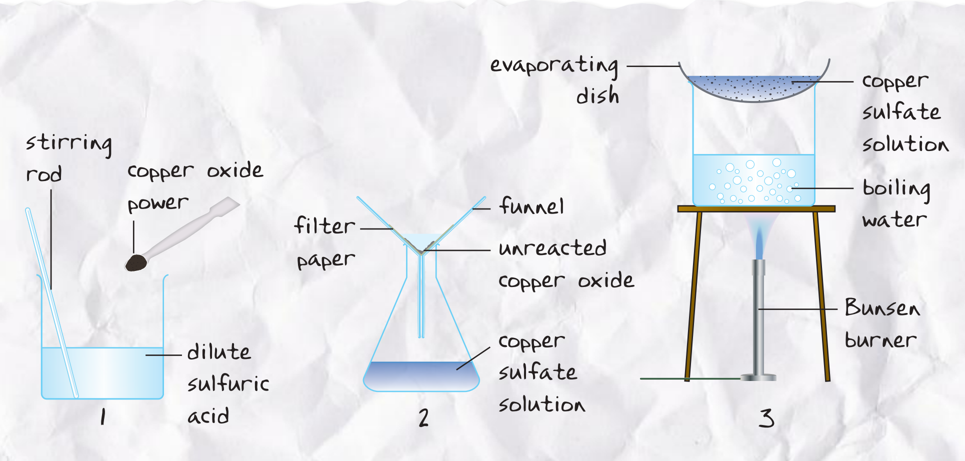
Making a salt

Maria uses the reaction in the equation above to make copper sulfate crystals. She writes down her plan.

1. Measure 25 cm^3 sulfuric acid into a beaker.
2. Add copper oxide powder, one spatula at a time, until no more reacts. This makes a solution of blue copper sulfate solution. It is mixed with black copper oxide powder that has not reacted.

3. Filter to separate copper oxide powder.
4. Heat the copper sulfate solution over a water bath. Stop heating when half its water has evaporated.
5. Leave the solution to stand for a few days. Copper sulfate crystals will form.

Maria draws and labels the apparatus she needs for each stage.



Maria finds out about the hazards in her experiment. She asks her teacher how to reduce the risks from each hazard.

Hazard	How to reduce risk from hazard
Copper oxide is harmful if swallowed. Dust irritates lungs and eyes.	Wear eye protection. Be careful when handling with spatula to prevent dust escaping.
Copper sulfate is harmful if swallowed. Solid irritates eyes and skin.	Wear eye protection. Do not touch with hands.
Glass makes sharp pieces if broken.	Place glass apparatus where it cannot roll off table.
Apparatus is hot.	Do not touch until cool.

Maria carries out her plan. A week later, she looks at her beautiful crystals!

Q

1 Write a word equation to show that iron and sulfur react to make iron sulfide.

2 Write a word equation to represent the combustion reaction of calcium.

3 Identify the reactants and products in the word equation below:
copper oxide + hydrochloric acid → copper chloride + water

4 In a chemical reaction, the reactants are magnesium and hydrochloric acid. The products are magnesium chloride and hydrogen. Write a word equation to represent the reaction.

!

In a word equation:

- the reactants are on the left of the arrow
- the products are on the right of the arrow
- the arrow means *reacts to make*.

7.3 Corrosion reactions

Objectives

- Understand what corrosion is
- Know how to prevent iron corroding

Reactions – useful or not?

Many chemical reactions are useful. Chemical reactions make medicines, fertilisers and cement. Combustion reactions release energy to cook food and make cars go. Chemical reactions keep living things alive.

But some chemical reactions are not useful. Read on to find out more.

Corrosion

This car is made from steel, which is mainly iron. It is covered in rust.

This roof is made from copper. Its surface is covered in green compounds called verdigris.

These forks are made from silver. Their surfaces are covered in black silver sulfide except for one, which has been cleaned.

Rust, verdigris, and silver sulfide are formed in **corrosion** reactions. A corrosion reaction is a chemical reaction that happens on the surface of a metal. Most corrosion reactions happen slowly – over days and weeks rather than seconds or minutes.

Iron corrosion

Iron corrosion, or **rusting**, is a big problem. It happens when iron reacts with oxygen and water. The oxygen comes from the air. The water may come from the air as vapour, or be in its liquid state.

The product of the rusting reaction is hydrated iron oxide. This is iron oxide with water joined loosely to it.

The word equation below summarises the rusting reaction:

iron + oxygen + water → hydrated iron oxide

Rust forms on the surface of iron. It is soft and crumbly. It easily comes off the surface of the metal. This leaves more iron exposed and ready to rust.

Copper corrosion

Over time, copper reacts with substances from the air, such as carbon dioxide. The reactions make green compounds, for example copper carbonate. The green compounds cover the surface of the copper. They do not easily come off, so the copper underneath is not damaged.

Silver corrosion

Silver does not react with oxygen or water at 20 °C. In clean air, it does not corrode.

Polluted air may contain hydrogen sulfide. Hydrogen sulfide reacts with silver. The product is a black compound – silver sulfide – which forms on the surface of silver.

This steel bucket has a coating of zinc.

Preventing corrosion

Steel is mainly iron. Most of the metal things we use are made from steel. So iron corrosion – rusting – is an expensive problem.

Oxygen and water make iron rust. We can prevent rusting by keeping oxygen and water away from iron. Chemists do this by coating iron with:

- paint (on cars)
- oil or grease (in engines)
- another metal.

Ben's bucket is made of steel. It is covered in zinc. Even if Ben scratches the zinc, the iron does not rust. The zinc reacts with oxygen instead of iron.

Not all metals corrode

Some metals do not corrode in the air. Gold and platinum do not react with substances from the air, or water. The elements stay shiny for thousands of years.

The surface atoms of a piece of tin react quickly with oxygen from the air. A thin layer of tin oxide forms on the surface of the tin. The tin oxide does not react with substances from the air, or water. The tin beneath is protected.

The word equation shows how the tin oxide layer is formed:

tin + oxygen → tin oxide

Aluminium metal is also covered by a layer of its oxide. The aluminium oxide protects the aluminium underneath. This aluminium cannot take part in reactions.

Aluminium is covered by a layer of aluminium oxide. It is not easily corroded.

Q

1. Name the two substances that react with iron to form rust.
2. Write a word equation to represent rusting.
3. Explain why rusting is a problem.
4. Describe three ways of preventing rusting, and explain how they each work.

!

- Iron rusts when it reacts with oxygen and water.
- Rust is hydrated iron oxide.

Enquiry

7.4

Doing an investigation

Objective

- Reinforce the stages of doing an investigation

Turning ideas into questions to test

A class plans to investigate rusting. Different students have different ideas.

Ruby

Seb

Tahlia

The students discuss how to turn their ideas into questions they can test.

Ruby thinks her idea is too big to investigate. She doesn't know where to start. She reads in a text book that iron needs air and water to rust. She writes down a question she can test.

> **Ruby** The textbook says that iron needs air and water to rust. Is this correct?

Seb reads that he is correct – salt does speed up rusting. He realises that his idea is too narrow. He wants to do an investigation that will give him plenty of data. He writes down a question to investigate.

> **Seb** How does the speed of rusting depend on the amount of salt?

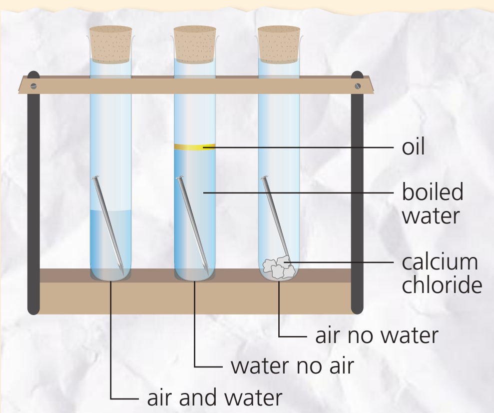
Tahlia knows she needs to narrow down her question. She collects evidence from a secondary source. She uses the evidence to help her write a question.

> **Tahlia** Which best prevents rusting – paint, grease, or covering iron in zinc?

Planning an investigation

Ruby plans her investigation. She draws her apparatus. She plans to leave the apparatus set up for a week. Then she will see which nails are rusty.

Before she starts, Ruby thinks about the variables in her investigation. She decides which to change, which to measure or observe, and which variables to control.



Variable	Change, measure/observe, or control?
Substance in contact with iron	change
Size of nail	control
Type of nail	control
Whether or not the nail goes rusty	observe

Ruby uses her scientific knowledge to make a prediction.

The nail in contact with both air and water will go rusty. The others will not. I predict this because iron reacts with oxygen and water to make rust (hydrated iron oxide).

Obtaining and presenting evidence

Ruby considers the hazards in her investigation. She decides how to reduce the risks from the hazards. Then she sets up her apparatus.

A week later, Ruby looks carefully at the nails in the test tubes. She writes her results in a table. The variable Ruby decided to change is in the left column. The variable she is observing is in the right column.

Substance in contact with iron	Has the nail gone rusty?
air only	no
water only	no
air and water	yes

Considering evidence

Ruby compares her results with her prediction. Her prediction is correct. She writes a conclusion, which includes a scientific explanation for her results.

The nail in contact with both air and water went rusty. The iron on the surface reacted with oxygen from the air, and water, to make hydrated iron oxide. This is rust. The equation for the reaction is:

iron + oxygen + water → hydrated iron oxide.

Q

1. Write a plan that Seb could use to collect evidence to help answer his question. Include a diagram, and identify the variables to change, observe, and control.
2. Write a plan to investigate Tahlia's question. Include a list of apparatus, and explain how to make the investigation fair.

!

Doing an investigation involves:

- developing a question
- planning, including identifying variables
- obtaining and presenting evidence
- considering evidence.

Extension 7.5

Using reactions to identify chemicals

Objective

- Know how to use chemical reactions to identify metal elements in compounds

Flame tests

It's festival time! Fireworks light up the sky. How do scientists give fireworks their colours?

Firework colours come from burning reactions of metal compounds. Different metals give different coloured flames.

You can use **flame tests** to help identify metal atoms in compounds:

1. Take a clean nichrome wire.
2. Dip the end of the wire in the compound you are testing.
3. Hold the end of the wire in a hot flame.
4. Observe the flame colour.

The pictures show the flame colours made by compounds of different metals.

Lithium compounds give a crimson flame.

Sodium compounds give a yellow flame.

Potassium compounds give a lilac flame.

Calcium compounds give a red flame.

Barium compounds give a green flame.

Metal hydroxide colours

Flame tests identify some metals in compounds, but not all. You can test with sodium hydroxide to identify some different metals in compounds.

Here is what to do:

1. Dissolve a small amount of the compound in pure water.
2. Add a few drops of sodium hydroxide solution.
3. Write down your observations.

You might see that a **precipitate** forms. A precipitate is a suspension of tiny solid particles in a liquid or solution. In this test, the precipitates are metal hydroxides. Different metal ions make precipitates of different colours.

The pictures show the colours of some precipitates.

Some metals form coloured precipitates when they react with sodium hydroxide. Here are (from left to right): iron(II) hydroxide, iron(III) hydroxide, copper hydroxide, and nickel hydroxide.

Iron forms two hydroxides:

- iron(II) hydroxide is green
- iron(III) hydroxide is brown.

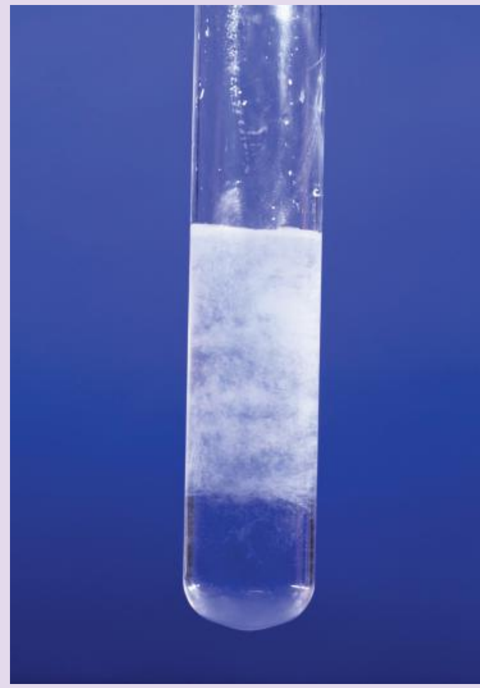
You can use word equations to summarise reactions that make precipitates. The equation below shows how to make a precipitate of copper hydroxide.

copper chloride + sodium hydroxide → copper hydroxide + sodium chloride

In the equation above:

- the reactants (copper chloride and sodium hydroxide) are solutions
- one product (sodium chloride) is a solution
- one product (copper hydroxide) is solid – it forms as a blue precipitate.

A student writes equations for three more reactions that make precipitates. Use the equations to answer question 3 below.



Precipitates of aluminium hydroxide, calcium hydroxide, and magnesium hydroxide are white.

1. iron(II) nitrate + sodium hydroxide → iron(II) hydroxide + sodium nitrate
2. iron(III) chloride + sodium hydroxide → iron(III) hydroxide + sodium chloride
3. aluminium chloride + sodium hydroxide → aluminium hydroxide + sodium chloride

Q

1 Describe how to do a flame test.

2 A compound burns with a yellow flame. Which metal atoms are in the compound?

3 **a** Give the colour of the precipitate formed in reaction 1 above.

b Name the precipitate formed in reaction 3 above.

4 Write a word equation for the reaction of iron(II) chloride with potassium hydroxide. Name the precipitate formed in the reaction, and give its colour.

!

- Flame tests help identify metal atoms in compounds
- Sodium hydroxide reacts with some salts to form coloured precipitates

Review 7.6

1 Copy and complete the word equations below.

a sodium + chlorine → ___________ [1]

b zinc + ___________ → zinc oxide [1]

c ___________ + sulfur → iron sulfide [1]

d iron + oxygen → ___________ [1]

e carbon + ___________ → carbon dioxide [1]

f ___________ + oxygen → sulfur dioxide [1]

2 What does the arrow (→) mean in a word equation? Choose the best answer from the four below:

are the same as **are equal to**

react to make **join up to make** [1]

3 Akono used to live in Abuja, a city far from the sea. He recently moved to Lagos, a city near the sea. He notices more rusty cars in Lagos. He wonders if salt speeds up rusting.

a Akono writes down three possible questions to investigate.

i Does salt speed up rusting?

ii What factors speed up rusting?

iii How does the mass of salt affect the speed of rusting?

Akono decides to investigate question iii. Identify one advantage of this question compared to question ii. [1]

b Akono lists some of the variables in his investigation to answer the question: *How does the mass of salt affect the speed of rusting?*

Variables:

– amount of salt

– how much of the nail has gone rusty?

– type of nail

– time nail is left in test tube

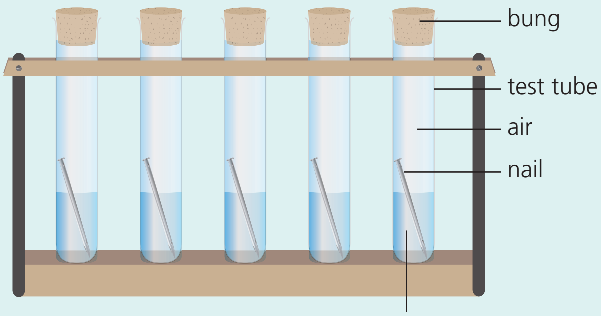
i From the list of variables above, identify the variable Akono should change. [1]

ii From the list of variables above, identify the variable Akono should measure. [1]

iii The list above includes two variables that Akono should control. Suggest one other variable that Akono should control. [1]

iv Explain why Akono should control the variables he is not changing or measuring. [1]

c Akono plans how to set up his apparatus.



Explain why the nail is in contact with both air and water. [1]

d Akono draws a table for his results. Copy and complete the missing column heading.

___________ (g)	How much of the nail has gone rusty?
0	
1	
2	
3	
4	

[1]

4 Name the reactants and products in the reactions shown by the word equations below.

a sodium + iodine → sodium iodide [2]

b carbon + oxygen → carbon dioxide [2]

c sulfuric acid + copper oxide → copper sulfate + water [2]

d magnesium + hydrochloric acid → magnesium chloride + hydrogen [2]

e copper carbonate → copper oxide + carbon dioxide [2]

5 Write word equations to summarise the reactions below.

a Heating sodium in bromine to make sodium bromide. [3]

b Heating sulfur in air to make sulfur dioxide. [3]

c Heating calcium carbonate so that it makes two products – calcium oxide and carbon dioxide. [3]

d Adding zinc to hydrochloric acid to make zinc chloride and hydrogen. [3]

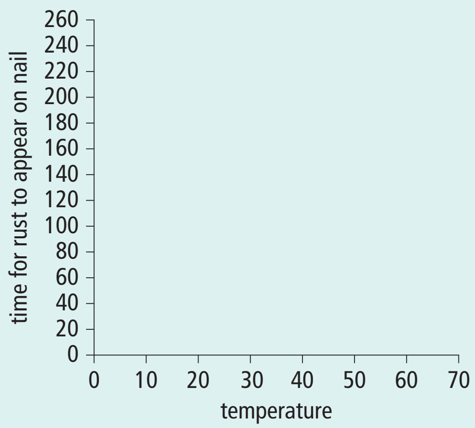
e Adding copper oxide to hydrochloric acid to make copper chloride and water. [3]

6 A scientist investigates the question: *How does temperature affect the speed of rusting?* She places six identical iron nails in boiling tubes. The nails are exposed to both air and water. She places each boiling tube in an oven or fridge at a different temperature. She observes the nails regularly.

Her results are in the table.

Temperature (°C)	Time for rust to appear on iron nail (hours)
10	240
20	120
30	100
40	30
50	15
60	7

a Finish labelling the axes on a copy of the graph axes below. [2]



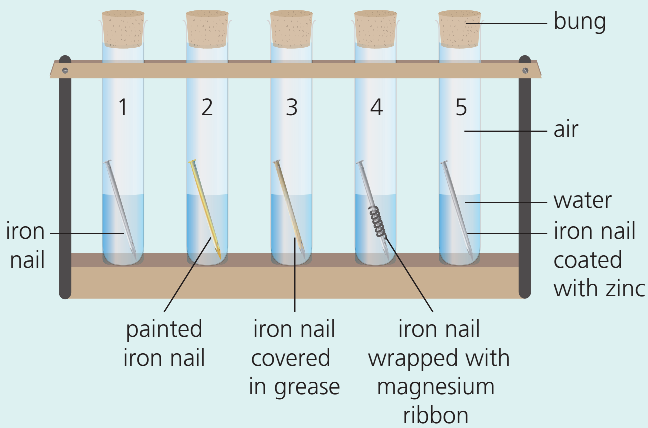
b Plot the data in the table onto your graph. [2]

c Draw a line of best fit on your graph. [1]

d Identify the anomalous result. [1]

e Suggest a reason for this result being anomalous. [1]

7 Purnomo sets up the apparatus below.



Copy and complete the table below. Predict the results you would expect for the investigation. Give a reason for each prediction. The second one has been done for you.

Test tube number	Prediction	Reason for prediction
1		
2	Nail will not rust.	Paint prevents air and water being in contact with the nail.
3		
4		
5		

[8]

Review
Stage 8

1 Use the words and phrases to copy and complete the sentences below. You may use each word or phrase once, more than once, or not at all.

vibrate on the spot **gas**
far apart **liquid**
move around from place to place
move around, in and out of each other
close together **solid**
a little **much**

Copper exists in three states, solid, liquid, and __________. In the solid state, its particles __________. The particles are __________. When copper melts, it changes state from __________ to __________. Its particles start to __________. They get __________ further apart.

If copper is heated to 1083 °C it changes from the liquid to the __________ state. Its particles get __________ further apart, and they start to __________. [10]

2 Match the names of the substances to their formulae.

Name
carbon dioxide
copper sulfate
carbon monoxide
nitrogen
helium

Formula
He
CO_2
N_2
$CuSO_4$
CO

[5]

3 Copy and complete the word equations below.

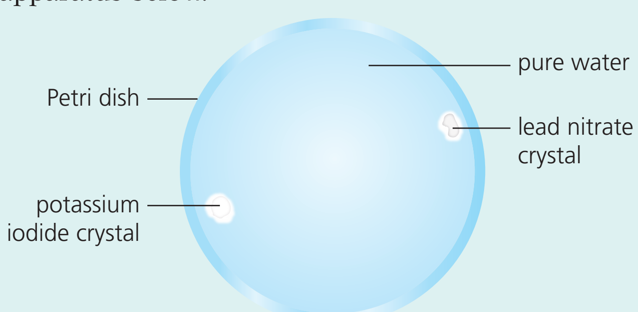
a __________ + bromine → iron bromide [1]

b copper + __________ → copper oxide [1]

c magnesium + chlorine → __________ [1]

d nitrogen + __________ → nitrogen dioxide [1]

4 Tamara investigates diffusion. She sets up the apparatus below.



The lead nitrate crystals and potassium iodide crystals are colourless. They dissolve in the water, and then diffuse.

a Explain what diffusion is. [1]

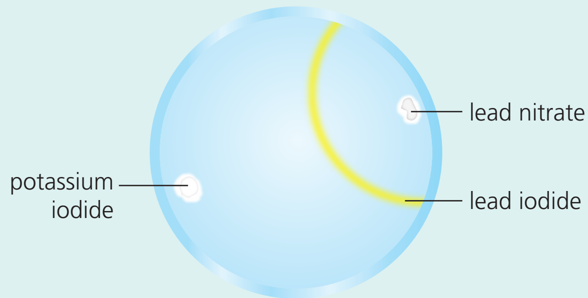
b As a result of diffusion, lead particles and iodide particles meet. They react to form a yellow solid. The yellow solid is called lead iodide.

i Name the reactants in the reaction. [1]

ii Name the product in the reaction. [1]

iii Write a word equation for the reaction. [3]

c The yellow solid forms along the line shown in the diagram below.



Choose the best two reasons from the list below to explain why solid lead iodide forms nearer the lead nitrate crystal than the potassium iodide crystal.

Reason 1: Lead particles have a greater mass than iodide particles.
Reason 2: The lead particles are at a higher temperature than the iodide particles.
Reason 3: Iodide particles diffuse more slowly than lead particles.
Reason 4: Lead particles diffuse more slowly than iodide particles. [2]

d Tamara wants to investigate how the rate of diffusion changes at different temperatures. She lists the important variables in her investigation.

- temperature
- time from adding crystals to formation of yellow solid
- amount of water
- size of lead nitrate crystal
- size of potassium iodide crystal

i Name the variable Tamara needs to change. [1]

ii Name the variable Tamara needs to measure. [1]

iii Explain why Tamara needs to control the other variables. [1]

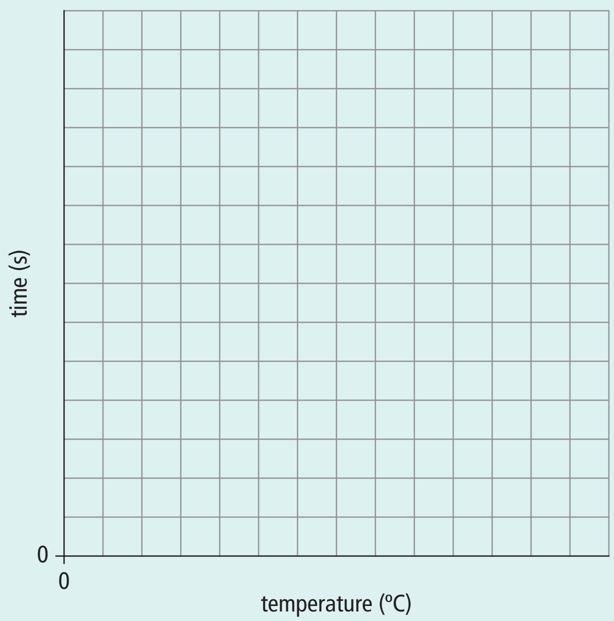
e Tamara writes a list of her results.

At 20 °C the precipitate formed after 60 seconds. When I used water at 30 °C it took 30 seconds. And then at 40 °C it was only 15. At 50 °C the time was about
14 seconds. And when the water was at 60 °C it only took 3 seconds to make the yellow solid.

i Write a table for Tamara's results. Include units in the column headings. [2]

ii Write Tamara's results in the table. [2]

f Copy and complete the axes below. Plot a graph of Tamara's results.



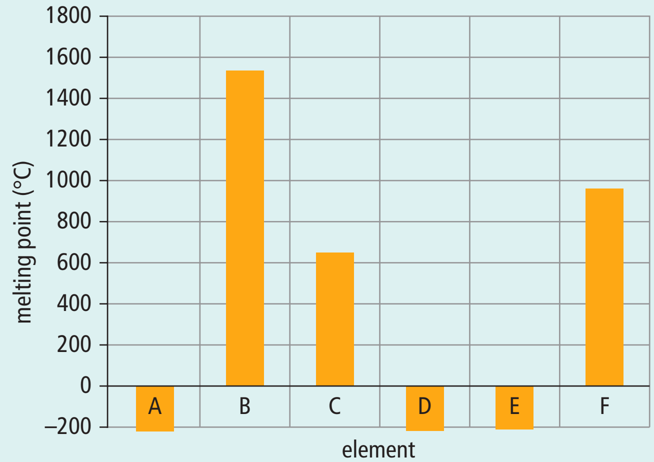
g Describe the correlation shown by the graph. [1]

h Identify the anomalous result on the graph. [1]

i What do you think Tamara should do about the anomalous result? Give a reason for your suggestion. [1]

j Write a conclusion for Tamara's investigation. Suggest a scientific reason that explains the correlation shown on the graph. [2]

5 The bar chart shows the melting points of some elements. Each element is represented by a letter. The letter is not the chemical symbol of the element.



a Give the letters of the three elements on the bar chart with the lowest melting points. [1]

b Give the letters of three elements on the bar chart which are most likely to be metals. [1]

c Give the letters of three elements on the bar chart which are least likely to conduct electricity. [1]

6 A student has a block of chromium. Its volume is 4 cm^3. It has a mass of 28 g. Use the equation below to calculate its density.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$ [3]

7 The table gives the melting and boiling points of some elements.

Element	Melting point (°C)	Boiling point (°C)
argon	-189	-186
bromine	-7.2	59
calcium	850	1487
gallium	30	2400
zirconium	1850	3580
technetium	2200	3500

a Which elements are in the solid state at 20 °C? [1]

b Which elements are in the liquid state at 40 °C? [1]

8.1 Atomic structure

Objectives

- Name three sub-atomic particles, and describe their properties
- Describe the structure of an atom

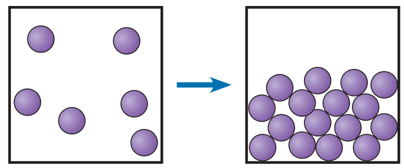
Models of atoms

No one can see inside an atom. Scientists have developed **models** of atoms. A scientific model describes an object or a system. It is simpler than the real object or system. Scientists use models to explain things that happen, or to make predictions.

Solid atoms

Until the early 1900s, scientists imagined atoms as solid spheres. This model is good enough to explain the behaviour of solids, liquids, and gases. It also explains diffusion, density, and gas pressure.

You can also use the solid atom model to make predictions. For example, how will a substance behave when it changes state from solid to liquid?



The solid atom model explains changes of state such as condensing.

But the solid atom model cannot explain everything in chemistry. It cannot explain how atoms join together. It cannot explain chemical reactions. Scientists need a more detailed model.

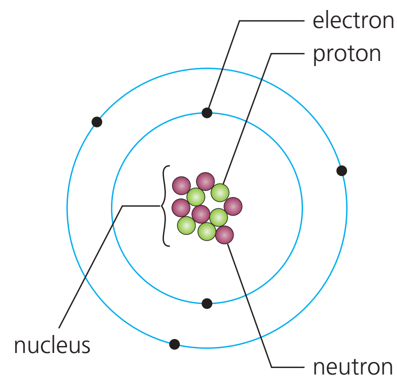
1932: a new model

In the early 1900s, scientists wanted to find out what is inside an atom. They collected evidence and thought about it creatively. You can find out more about what they did on pages 148–9.

By 1932, scientists had developed a new model. The model explains how atoms join together. It also explains chemical reactions.

The model states that atoms are made up of tiny **sub-atomic particles**. There are three types of sub-atomic particle – **protons**, **neutrons**, and **electrons**.

Protons and neutrons make up the nucleus. The **nucleus** is in the centre of an atom. Electrons whizz around the outside.



Atoms are made up of three types of sub-atomic particle: protons, neutrons, and electrons. *Not to scale.*

More on sub-atomic particles

The table gives the masses and charges of protons, neutrons, and electrons.

Type of sub-atomic particle	Relative mass	Charge
proton	1	+1
neutron	1	0
electron	$\frac{1}{1840}$	-1

The table compares the masses of protons, neutrons, and electrons. Their actual masses are tiny. The mass of a proton is about:

0.000 000 000 000 000 000 000 000 001 7 kg

The mass of an electron is even smaller.

Almost all the mass of an atom is in its nucleus. But a nucleus is tiny compared to its atom. This means that a nucleus has a very high density. For example, the density of a fluorine atom nucleus is about 60 000 000 000 000 g/cm^3.

A nucleus is tiny compared to its atom. If you imagine an atom to be the size of a football stadium, the nucleus is the size of a pea.

Why do atoms have no electric charge?

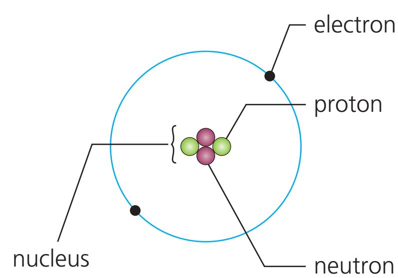
Atoms contain charged particles. But atoms have no overall electrical charge. They are neutral. This is because, in any atom, the number of protons is the same as the number of electrons.

For example, a helium atom is made up of:

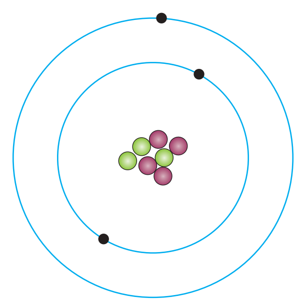
- 2 positive protons
- 2 negative electrons
- 2 neutral neutrons.

A lithium atom is made up of:

- 3 positive protons
- 3 negative electrons
- 4 neutral neutrons.



A helium atom. *Not to scale.*



A lithium atom. *Not to scale.*

Q

1. Give the relative charge and mass of each of the following: a proton, a neutron, and an electron.
2. Name the two types of sub-atomic particle in the nucleus of an atom.
3. Draw a beryllium atom. It is made up of four protons, four electrons, and five neutrons.
4. Explain why a beryllium atom is electrically neutral.

!

- Atoms are made up of sub-atomic particles called protons, neutrons, and electrons.
- Protons and neutrons make up the nucleus of an atom. Electrons whizz around the outside.

Enquiry

8.2

Finding electrons

Objective

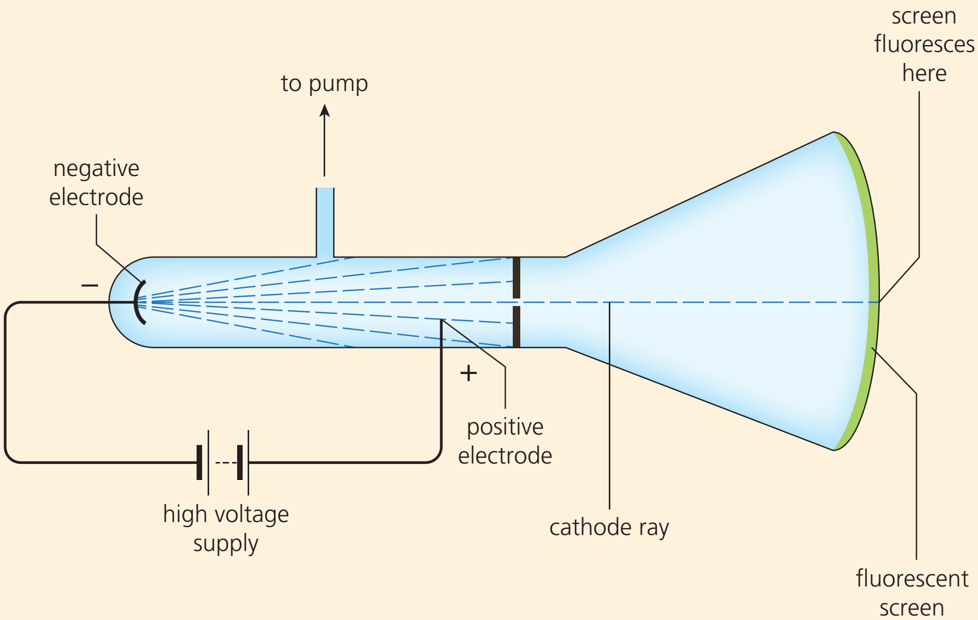
- Describe how scientists work using historical examples

Scientists cannot look inside atoms. So how did they discover sub-atomic particles? How did they create the models of atomic structure that we use today?

Finding electrons

In the late 1800s scientists investigated gases. They took sealed tubes containing tiny amounts of gas. They set up an electric circuit and supplied huge voltages.

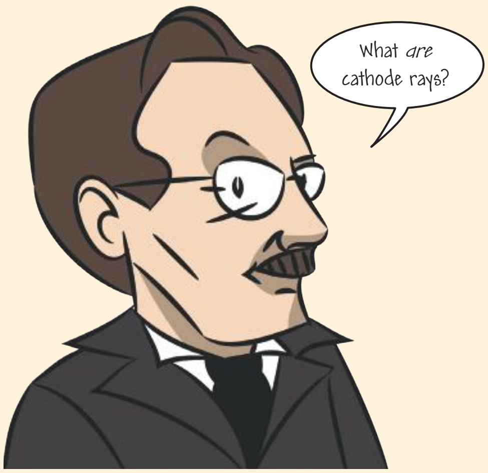
Amazingly, the gases conducted electricity. In 1869 Johann Hittorf noticed a green glow on the screen. The glow, he said, was caused by rays from the negative electrode. The rays travelled through the gas and hit the screen. These were cathode rays.



When the voltage is high, cathode rays travel through the gas.

Scientist Joseph John Thomson thought about cathode rays. He asked a question.

Thomson thought creatively about his question. He suggested an explanation. Maybe cathode rays are electrically charged.



Thomson collected evidence to test his idea. He passed cathode rays between electrically charged pieces of metal. The rays bent towards the positively charged metal.

Thomson was pleased. The evidence supported his explanation. Cathode rays are charged. Their charge is negative.

Thomson asked more questions. He did some more thinking. He collected more evidence. He concluded that cathode rays are made up of particles. All the particles have the same – tiny – mass. They all have the same electrical charge. By 1897 Thomson had discovered the first sub-atomic particle, the electron.

Ask a question
What are cathode rays?

↓

Suggest an explanation
Maybe cathode rays are electrically charged.

↓

Test the explanation
Pass cathode rays through electrically charged pieces of metal. If they bend towards the positively charged metal, they have a negative electrical charge.

↓

Check the evidence
Does it support the explanation?

NO → There must be a different explanation. → (back to Suggest an explanation)

YES ↓

The explanation is accepted.

Thomson found out that cathode rays are negatively charged by asking a question, thinking creatively, and collecting evidence.

New models of the atom

Scientists thought about electrons. They knew that electrons come from materials. Materials are made up of atoms. Electrons must be part of atoms.

Scientists suggested models for the atom.

Thomson's plum pudding model

Thomson knew that electrons are negatively charged. He also knew that atoms have no overall electrical charge.

In 1904, Thomson used this evidence to suggest a new atomic model. Negative electrons, he said, are placed throughout a positively-charged sphere. The electrons move around in rings.

Other people called Thomson's model the plum pudding model. The electrons reminded people of plums in a pudding.

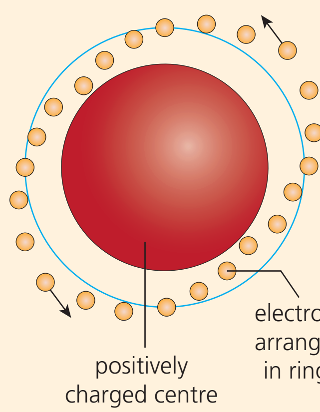
Nagaoka's Saturn model

Hantaro Nagaoka was a Japanese scientist. He thought about the evidence for Thomson's model. He read about evidence collected by other scientists.

Thomson's model, said Nagaoka, could not be correct. It is not possible for negative charges to be spread out in a positively-charged sphere.

In 1904, Nagaoka suggested a new model. An atom consists of a positively-charged centre. Electrons orbit around the centre in rings, like those of the planet Saturn. Nagaoka used his model to predict that an atom has a nucleus with a large mass.

The story of the discovery of atomic structure does not end here. Turn the page to find out more.



Nagaoka imagined an atom as having a positively-charged centre surround by electrons in rings, like those of Saturn.

Q

1 Thomson suggested that cathode rays are electrically charged. Describe the evidence that supports this explanation.

2 Compare Thomson's plum pudding model with Nagaoka's Saturn model.

3 Explain why Nagaoka thought that Thomson's model for the structure of an atom is incorrect.

!

To develop explanations, scientists:

- ask questions
- use creative thought
- do experiments and make observations to collect evidence.

8.3 Discovering the nucleus

Objective

- Describe the method and discoveries of Rutherford

Testing the plum pudding model

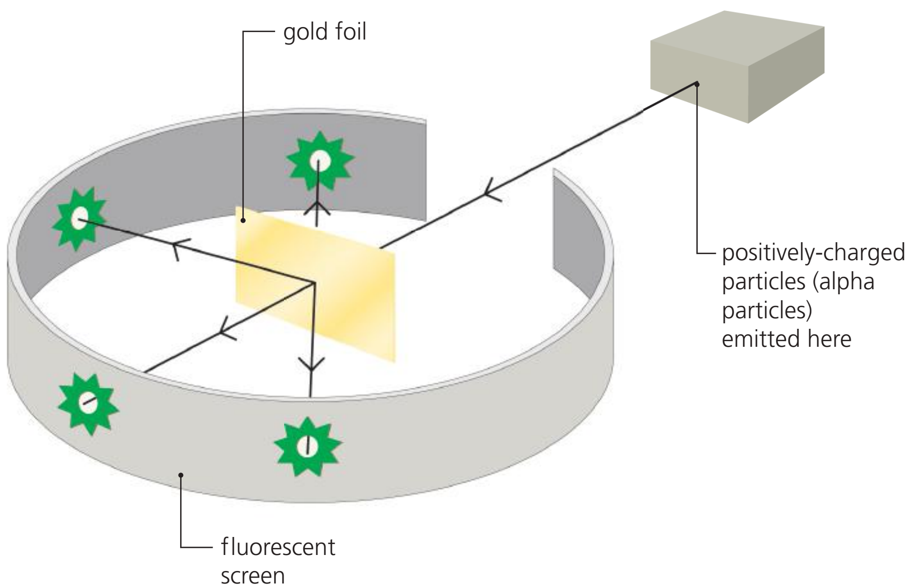
Scientists thought about Thomson's plum pudding model. There was good evidence for the existence of negatively-charged electrons. But what about their arrangement in a positively-charged sphere? Was there evidence for this?

Ernest Rutherford lived and studied in New Zealand until he was 23. In 1895, he moved to Cambridge, England, to study under Thomson. He later worked in universities in Montreal, Canada, and Manchester, England.

Rutherford wanted to test Thomson's plum pudding model. He made a prediction, based on the model.

> We are going to fire positively-charged particles at a piece of gold foil. If the plum pudding model is correct, most of the positive particles will go straight through the foil. A few will pass close to negative electrons. These positive particles will change direction slightly.

Rutherford worked with two other scientists to test his prediction. The scientists, Hans Geiger and Ernest Marsden, set up the apparatus below.



Geiger and Marsden used this apparatus to test the plum pudding model in 1909.

The scientists started firing positive particles at the foil. The results were amazing. About one positive particle in every 10 000 bounced backwards off the foil. Rutherford wrote:

> It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15 inch [38 cm] artillery shell at a piece of tissue paper and it came back and hit you.

Rutherford evaluated the evidence. His prediction was wrong. He had based his prediction on the plum pudding model. This, said Rutherford, means the plum pudding model must be wrong.

Rutherford thought creatively about the problem. Could he come up with a better model to explain the evidence?

A new model for the atom

By 1911, Rutherford had created a new model:

- Atoms have a central nucleus. Most of the mass of an atom is in its nucleus. The nucleus is positively charged.
- The nucleus is surrounded by a big empty space in which electrons move.

Rutherford's model explained Geiger and Marsden's observations:

- The positive particles that bounced backwards had hit a nucleus.
- The positive particles that travelled straight through the foil had passed through empty space between nuclei.

Rutherford told other scientists about his work. Niels Bohr wondered how electrons move in the empty space around a nucleus. He suggested an explanation. Electrons move in orbits, or shells.

Inside the nucleus

Scientists thought about the nucleus. Was it made up of smaller particles?

Rutherford collected evidence. He fired positive particles into the air. Tiny positive particles were formed. Where did they come from? Rutherford realised that the tiny positive particles came from the nuclei of nitrogen atoms. The tiny particles were protons.

A year later, in 1920, Rutherford suggested that protons were not the only particles in the nucleus. Did nuclei also contain particles with mass, but no charge?

By 1932, James Chadwick had an answer. His experiments showed that nuclei contain neutrons as well as protons.

In chemistry, you will use the atomic model of 1932. This explains chemical reactions. It also explains patterns in the properties of elements.

Scientists did not stop studying the atom in 1932. They wanted to find out what makes up protons and electrons. Turn to pages 166–7 to find out more.

Q

1 Describe Rutherford's model of the atom.
2 Describe how Rutherford, Geiger, and Marsden collected evidence for the nucleus.
3 Describe Rutherford's evidence for protons.

!

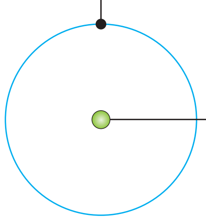
Rutherford discovered that:

- atoms have a central nucleus
- most of the mass of an atom is in its nucleus
- the nucleus contains protons.

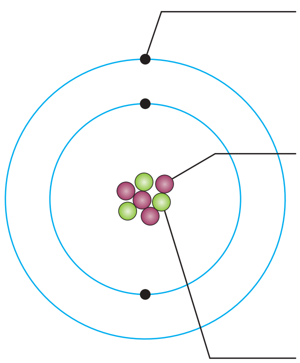
8.4 Protons, electrons, and the periodic table

Objectives

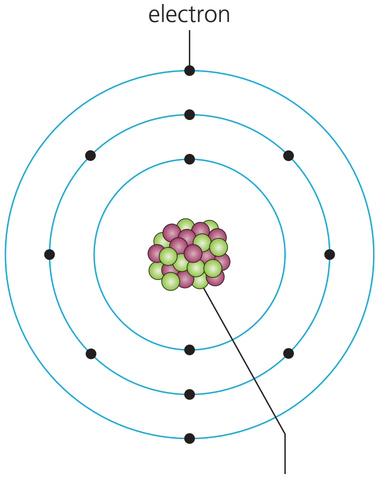
- Draw the structures of atoms of the first 20 elements
- Describe patterns in the structures of these atoms



The electron in a hydrogen atom.



The electrons in a lithium atom.



The electrons in a magnesium atom.

Protons

The nucleus of an atom is made up of protons and neutrons. All atoms of an element have the same number of protons. For example, all oxygen atoms have eight protons, and all nitrogen atoms have seven protons.

In the modern periodic table, the elements are arranged in order of their number of protons.

Electrons in atoms

Electrons whizz around an atom outside its nucleus. The electrons occupy **shells**. Shells are also called **energy levels**, or **orbits**.

Each shell can hold a maximum number of electrons:

- the first shell can hold up to two electrons
- the second shell can hold up to eight electrons.

Electrons fill the shells that are closest to the nucleus first.

Hydrogen has one electron. It occupies the first shell.

Lithium has three electrons. Two electrons occupy the first shell. This shell is full. The other electron occupies the second shell.

A magnesium atom has 12 electrons. Two electrons occupy the first shell. Eight electrons occupy the second shell. The first two shells are now full. The other two electrons are in the third shell.

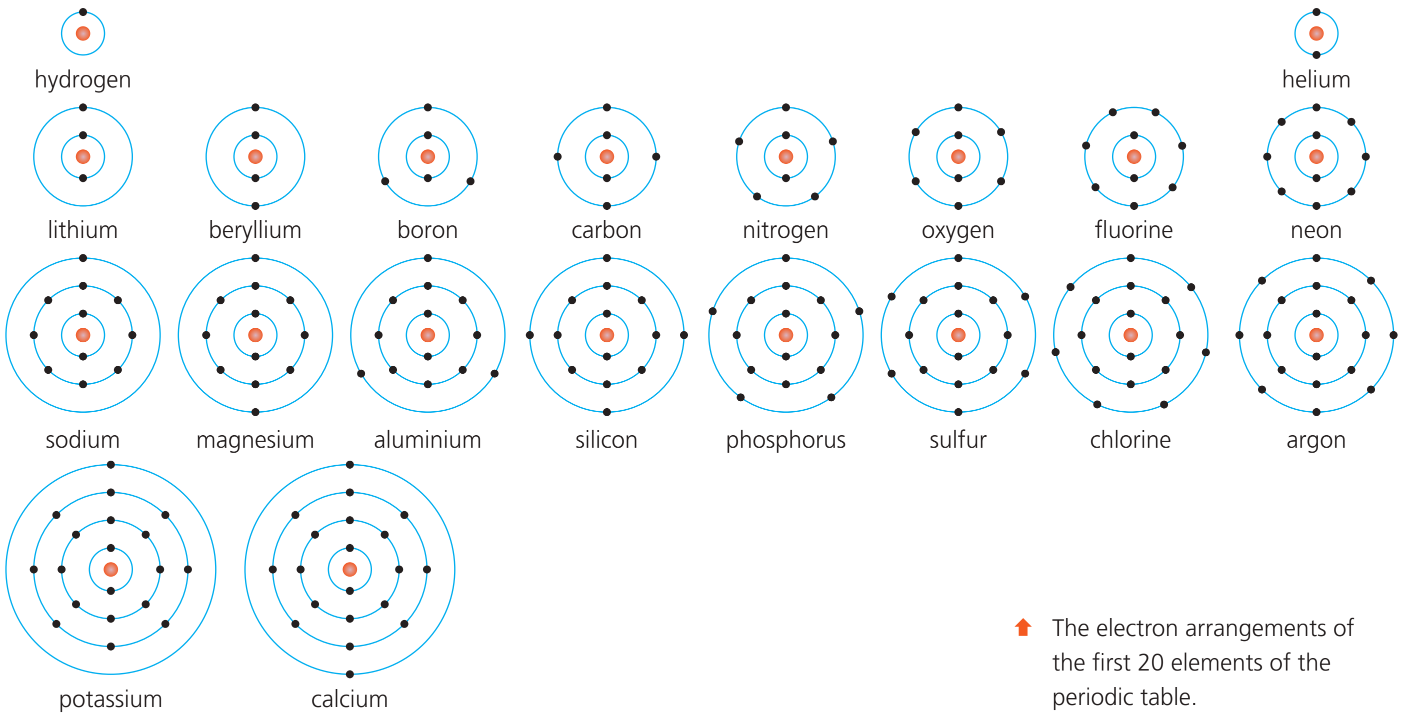
You can also use numbers to represent electron arrangements. The numbers show the **electronic structure** of an atom. The first number of an electronic structure shows the number of electrons in the first shell. The second number gives the number of electrons in the second shell, and so on.

The table shows the electronic structures of the atoms drawn opposite.

Element	Number of electrons	Electronic structure
hydrogen	1	1
lithium	3	2,1
magnesium	12	2,8,2

The first twenty elements

The diagrams on the next page show the electrons in the atoms of the first 20 elements of the periodic table. They do not show the number of protons and neutrons.



The electron arrangements of the first 20 elements of the periodic table.

The diagram below gives the symbols and electronic structures of the first 20 elements of the periodic table. The elements are arranged as they are in the periodic table.

H 1							
							He 2
Li 2,1	**Be** 2,2	**B** 2,3	**C** 2,4	**N** 2,5	**O** 2,6	**F** 2,7	**Ne** 2,8
Na 2,8,1	**Mg** 2,8,2	**Al** 2,8,3	**Si** 2,8,4	**P** 2,8,5	**S** 2,8,6	**Cl** 2,8,7	**Ar** 2,8,8
K 2,8,8,1	**Ca** 2,8,8,2						

Can you see a pattern in the electronic structures? The elements in the column on the left (Group 1 of the periodic table) have one electron in their outermost shell (the shell that is furthest from the nucleus). The elements in the next column (Group 2) have two electrons in their outermost shell. In all groups, atoms of each element have the same number of electrons in their outermost shell.

Q

1 Draw the electron arrangements in atoms of lithium, sodium, and potassium. Describe what the arrangements have in common.

2 Write down the electronic structures of helium, neon, and argon. Describe how the arrangements are similar.

3 Write down the electronic structures of the elements from lithium to neon in the periodic table. Describe the pattern you see.

!

- Electrons in atoms are arranged in shells.
- Each shell holds a maximum number of electrons.

Extension 8.5

Proton number, nucleon number, and isotopes

Objectives

- Work out the proton number and nucleon number of an atom
- Explain what isotopes are

Proton number

Every atom of hydrogen has one proton in its nucleus. Every atom of oxygen has eight protons in its nucleus. Every atom of magnesium has 12 protons in its nucleus.

The number of protons in the nucleus of an atom is its **proton number**. The table gives the proton numbers of some elements. Every atom of a certain element has the same proton number.

Element	Proton number
hydrogen	1
oxygen	8
magnesium	12

In modern periodic tables, elements are arranged in order of proton number.

			1.0 H hydrogen 1														4 He helium 2
7 Li lithium 3	9 Be beryllium 4											11 B boron 5	12 C carbon 6	14 N nitrogen 7	16 O oxygen 8	19 F fluorine 9	20 Ne neon 10
23 Na sodium 11	24 Mg magnesium 12											27 Al aluminium 13	28 Si silicon 14	31 P phosphorus 15	32 S sulfur 16	35.5 Cl chlorine 17	40 Ar argon 18
39 K potassium 19	40 Ca calcium 20	45 Sc scandium 21	48 Ti titanium 22	51 V vanadium 23	52 Cr chromium 24	55 Mn manganese 25	56 Fe iron 26	59 Co cobalt 27	59 Ni nickel 28	63.5 Cu copper 29	65 Zn zinc 30	70 Ga gallium 31	73 Ge germanium 32	75 As arsenic 33	79 Se selenium 34	80 Br bromine 35	84 Kr krypton 36
85.5 Rb rubidium 37	88 Sr strontium 38	89 Y yttrium 39	91 Zr zirconium 40	93 Nb niobium 41	96 Mo molybdenum 42	(98) Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
133 Cs caesium 55	137 Ba barium 56	139 La lanthanum 57	178.5 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 Tl thallium 81	207 Pb lead 82	209 Bi bismuth 83	210 Po polonium 84	(210) At astatine 85	222 Rn radon 86
(223) Fr francium 87	(226) Ra radium 88	(227) Ac actinium 89	(261) Rf rutherfordium 104	(262) Db dubnium 105	(266) Sg seaborgium 106	(264) Bh bohrium 107	(277) Hs hassium 108	(268) Mt meitnerium 109	(271) Ds Darmstadtium 110	(272) Rg roentgenium 111							

Note: This periodic table does not include all the elements.

For each element, the lower number is the proton number. The upper number gives the relative atomic mass of the element.

Atoms are neutral. This is because an atom has an equal number of protons and electrons. So the proton number of an element tells you the number of protons, which is also the number of electrons in one atom of the element.

Nucleon number

Protons and neutrons make up the nucleus of an atom. Particles in the nucleus – protons and neutrons – are called **nucleons**. The total number of protons and neutrons in an atom is its **nucleon number**. For example, an atom of oxygen has eight protons and eight neutrons. Its nucleon number is sixteen.

The nucleon number of an atom is also called its **mass number**. It gives the relative mass of an atom compared to other atoms.

The table gives the numbers of protons and neutrons in some atoms. It also shows their nucleon numbers.

Atom of the element	Number of protons	Number of neutrons	Nucleon number
fluorine	9	10	(9 + 10) = 19
magnesium	12	12	(12 + 12) = 24
argon	18	22	(18 + 22) = 40

If you know the proton number and the nucleon number of an atom, you can work out how many protons and neutrons are in its nucleus.

Worked example

An atom of boron has a proton number of 5 and a nucleon number of 11. How many protons and neutrons does it contain?

The proton number shows that the number of protons in a boron atom is 5.

The number of neutrons = nucleon number – proton number

= 11 – 5

= 6

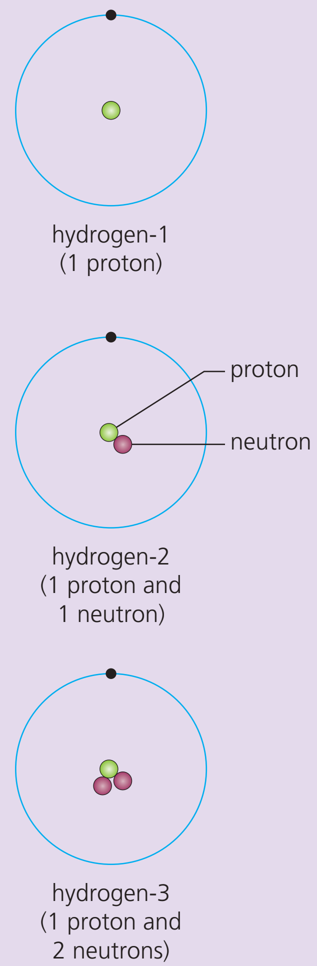
Isotopes

Every carbon atom has 6 protons. Every carbon atom also has 6 electrons. Most carbon atoms have 6 neutrons. However, some carbon atoms have 8 neutrons, and some have 7 neutrons.

Atoms of the same element that have different numbers of neutrons are called **isotopes**. The different isotopes of an element have different nucleon numbers. The table shows the nucleon numbers of the three isotopes of carbon.

Atom of the element…	Number of protons	Number of neutrons	Nucleon number
carbon	6	6	12
carbon	6	7	13
carbon	6	8	14

Every chlorine atom has 17 protons and 17 electrons. About 75% of chlorine atoms have 18 electrons. The other 25% of chlorine atoms have 20 electrons. There are two isotopes of chlorine. The nucleon number of one isotope is (17 + 18) = 35. The nucleon number of the other isotope is (17 + 20) = 37.



Hydrogen has three isotopes.

Q

1 Explain what an isotope is.
2 An atom of an element has 15 protons and 16 neutrons. What is its proton number? What is its nucleon number?
3 An atom has a proton number of 19 and a nucleon number of 39. Calculate the number of protons and neutrons in the atom.

!

- Proton number is the number of protons in an atom of an element.
- Nucleon number is the total number of protons and neutrons in an atom of an element.
- Isotopes are atoms of the same element with different numbers of neutrons.

8.6 The Group 1 elements

Objective

- Describe trends in properties of the Group 1 elements

The Group 1 elements

The columns of the periodic table are called **groups**. The elements of a group have similar properties to each other.

The periodic table below shows Group 1. The group includes the elements lithium, sodium, and potassium.

Lithium and its compounds are used in cell phone batteries.

Group 1

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

Group 1 is on the left of the periodic table.

This nuclear power station in Kalpakkam, India, uses sodium metal as a coolant.

Properties and patterns

The Group 1 elements are metals. In some ways, they are like other metals:

- they conduct electricity
- they are shiny when freshly cut.

The Group 1 elements are softer than most other metals. They can be easily cut with a knife.

Group 1 metals are soft.

Melting point and boiling point

The Group 1 elements have low melting points compared to most other metals. The table gives some examples.

Metal	Is the metal in Group 1?	Melting point (°C)
lithium	yes	180
sodium	yes	98
potassium	yes	64
rubidium	yes	39
iron	no	1535
copper	no	1083
gold	no	1063

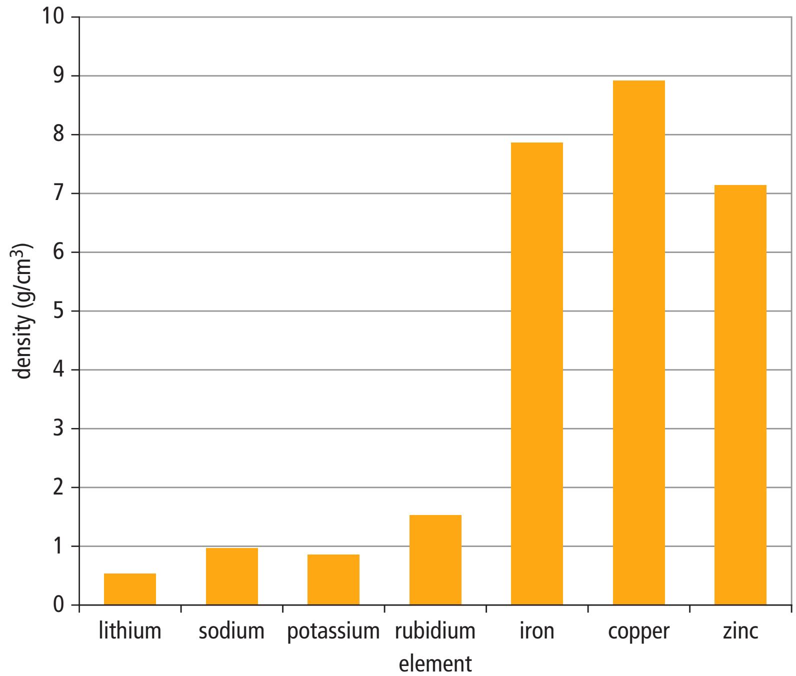
There is a pattern in the melting points of the Group 1 elements. Going down the group, from lithium to rubidium, melting point decreases. A gradual change in a property is called a **trend**.

The boiling points of the Group 1 elements also decrease from top to bottom of the group.

Density

The Group 1 elements have low densities compared to most other metals. A 1 cm^3 cube of sodium has a mass of 0.97 g. Iron has a much higher density than sodium. A 1 cm^3 cube of iron has a mass of 7.86 g.

This bar chart compares the densities of Group 1 elements with three other metals.



The bar chart shows a trend in density values for the Group 1 elements. Overall, going down the group, from lithium to caesium, density increases. The density of potassium does not fit the pattern.

Reactions with water

The Group 1 elements have exciting reactions with water. As they react, they zoom around on the surface of the water. The reactions make hydrogen gas and an alkaline solution. Universal Indicator solution becomes blue or purple in the solution.

These word equations summarise the reactions of sodium and potassium with water:

sodium + water → sodium hydroxide + hydrogen

potassium + water → potassium hydroxide + hydrogen

There is a trend in these reactions. They get more vigorous going down the group.

Why do Group 1 elements have similar properties?

The atoms of the Group 1 elements have similar electron arrangements. They all have one electron in the outermost shell. This explains their similar properties.

Q

1. Describe the trend in melting point for the Group 1 elements.
2. Describe the trend in density for the Group 1 elements.
3. Write word equations to summarise how three Group 1 elements react with water. Describe the trend in these reactions.

!

From top to bottom of Group 1:

- melting point and boiling point decrease
- density increases, overall
- the reactions with water get more vigorous.

8.7 The Group 2 elements

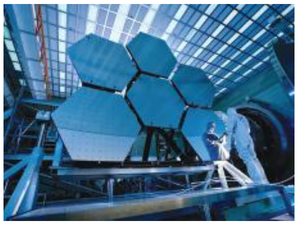
Objective

- Describe trends in the properties of Group 2 elements

A rare element

What links the items in the pictures?

An emerald from India.



Part of the James Webb Space Telescope.

Special tools for using on an oil rig.

They all include beryllium. Beryllium is joined to other elements in the main compound of emerald.

The space telescope has 18 beryllium mirrors. Beryllium has perfect properties for this job. It is shiny, has a low density, and does not change shape at low temperatures.

An alloy of two metals – beryllium and copper – is used to make tools for workers on oil rigs. The alloy is strong and will not be damaged by seawater. It will also not cause sparks that could start a fire on an oil rig.

The Group 2 elements

Beryllium is in Group 2 of the periodic table. The other members of the group are magnesium, calcium, strontium, barium, and radium.

	Group 2																
							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

Group 2.

The electronic structures of some Group 2 elements are shown below:

beryllium	2,2
magnesium	2,8,2
calcium	2,8,8,2

The atoms of all Group 2 elements have 2 electrons in their outermost shell. Their similar electron arrangements give the elements similar properties.

Reactions with water

Calcium reacts vigorously with water. The products are hydrogen gas and calcium hydroxide solution:

calcium + water → calcium hydroxide + hydrogen

Strontium and barium react even more vigorously with water. The products are similar:

strontium + water → strontium hydroxide + hydrogen

barium + water → barium hydroxide + hydrogen

Magnesium does not react vigorously with water. If you put a piece of magnesium ribbon in a test tube of cold water, tiny hydrogen bubbles form slowly on its surface.

The reactions of Group 2 metals with water show a trend. They get more vigorous going down the group. The Group 1 metals show a similar trend (see page 157).

Calcium reacts vigorously with water.

Reactions with acid

The Group 2 elements react with dilute hydrochloric acid. Smita wants to answer this question:

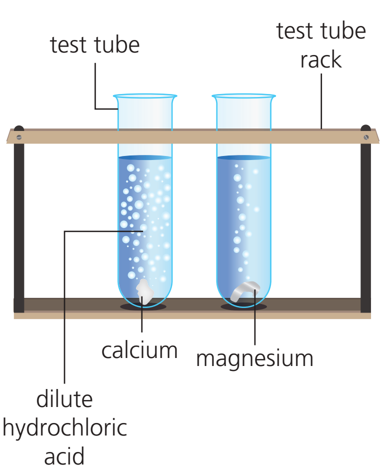
Which reacts more vigorously with acid – magnesium or calcium?

She makes a prediction, based on her scientific knowledge.

I predict that calcium will react more vigorously than magnesium. I think this because the reactions of the Group 2 metals with water get more vigorous going down the group.

Smita sets up the apparatus opposite.

Both reactions produce bubbles of hydrogen gas. The reaction of calcium is more vigorous. Smita's prediction is correct.



Calcium and magnesium reacting with dilute hydrochloric acid.

Q

1. Write word equations for the reactions of calcium, strontium, and barium with water.
2. Predict how beryllium reacts with water, compared to the other elements of the group.
3. Suggest how you could investigate which reacts more vigorously with dilute hydrochloric acid – beryllium or magnesium.

!

From top to bottom of Group 2:

- the reactions of the elements with water get more vigorous
- the reactions of the elements with acids get more vigorous.

8.8 The Group 7 elements

Objective

- Describe trends in the properties of Group 7 elements

Iodine solution destroys bacteria around cuts.

Deadly elements

Chlorine gas killed 5000 people in the First World War. Fluorine poisons all living things. Fluorine, chlorine, bromine, and iodine destroy bacteria.

These deadly elements can also save lives. Chlorine and its compounds destroy viruses and bacteria in water, making it safe to drink. Iodine solution destroys bacteria around cuts.

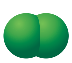
Fluorine, chlorine, bromine, and iodine are in Group 7 of the periodic table. They are the **halogens**.

Group 7 the halogens

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

Group 7 is towards the right of the periodic table.

Group trends



A chlorine molecule, Cl_2.

The Group 7 elements are non-metals. They do not conduct electricity. They are poor conductors of heat.

The table shows some properties of the Group 7 elements.

Element	Melting point (°C)	Boiling point (°C)	State at 20 °C	Colour
fluorine	-220	-188	gas	yellow
chlorine	-101	-35	gas	green
bromine	-7	59	liquid	dark red
iodine	114	184	solid	solid – shiny grey-black vapour – purple

The Group 7 elements have low melting and boiling points compared to most metals. This is because they exist as molecules.

A strong force holds the two atoms of the molecule together. The forces between a molecule and its neighbours are weak. It is easy to separate the molecules of chlorine in the liquid state to form a gas.

The table above shows a trend in melting and boiling points. They increase from top to bottom of the group. This is because the atoms (and molecules) of the elements get bigger.

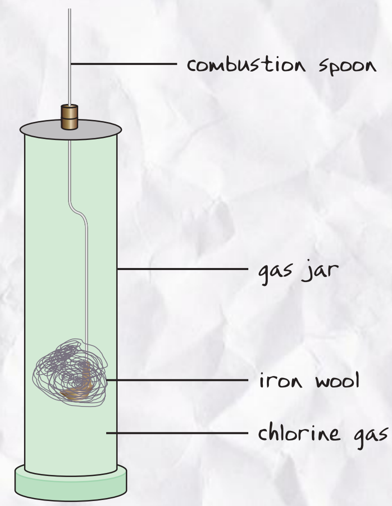
Reactions of the Group 7 elements

Mr Ali is planning to teach about trends in the reactions of Group 7 elements. He decides to show his students how the elements react with iron.

Mr Ali sketches some apparatus.

Mr Ali writes down some hazards of some of the substances in the reactions. He notes how to control the risks from these hazards.

substance	hazards	how to control risks from hazard
chlorine gas	• toxic	• use a fume cupboard • wear eye protection
bromine liquid	• very toxic • corrosive	• use a fume cupboard • wear eye protection • wear gloves



Apparatus for reacting a Group 7 element with iron.

Mr Ali thinks about the risks. He does not have a fume cupboard to remove toxic gases from the laboratory. He decides not to demonstrate the reactions himself. His students will not learn about the reactions from first-hand experience. Instead, he will show videos of the reactions. His students will learn about the reactions from secondary sources.

A student watches the videos. She writes down her observations.

Reactants	Observations	Word equation
iron and chlorine	Very fierce reaction. Bright flame. Makes brown solid.	iron + chlorine → iron chloride
iron and bromine	Less fierce reaction.	iron + bromine → iron bromide
iron and iodine	Even less fierce reaction.	iron + iodine → iron iodide

The reactions are similar. This is because all the Group 7 elements have seven electrons in the outermost shell.

For the Group 7 elements, reactions get less vigorous going down the group. This is different from Groups 1 and 2, in which the reactions get more vigorous going down the group.

Q

1. Describe and explain the trends in melting and boiling point for the Group 7 elements.
2. Write word equations for the reactions of three Group 7 elements with iron. Describe how the vigour of these reactions changes from top to bottom of the group.

!

From top to bottom of Group 7:

- melting point and boiling point increase
- the reactions with iron get less vigorous.

Enquiry
8.9

Looking at secondary data – chlorinating water

Objective

- Look critically at sources of secondary data

Why add chlorine?

Dirty water kills. The World Health Organization estimates that 3.4 million people die every year from diseases that are spread by untreated water. The diseases include cholera, typhoid fever, and dysentery.

Adding chlorine to drinking water destroys the bacteria, viruses, and parasites that cause these diseases. However, people have not always known this.

In 1894 a German scientist, Moritz Traube, investigated the effects of adding calcium chloride to bacteria-rich water. After two hours, the bacteria had been destroyed. The water was safe to drink.

Since 1900, chlorine and its compounds have been added to drinking water in many places. Fewer people have died from waterborne diseases.

Adding chlorine and its compounds to water destroys disease-causing microbes.

A dangerous by-product?

When chlorine is added to water, it may react with substances dissolved in water. The products are trihalomethanes (THMs). Drinking THM-containing water may slightly increase the risk of cancer.

Studying the effects of chlorinated water

Asking a question

Scientists from West Bengal, India, decided to investigate the long-term effects of drinking chlorinated water. They asked a question:

What are the health effects of drinking chlorinated drinking water?

Obtaining evidence

The scientists, Ritesh Sharma and Sudha Goel, collected evidence from three groups of people:

- Group 1 had been drinking chlorinated water for at least 30 years.
- Group 2 had had little access to chlorinated water at home.
- Group 3 had had no access to chlorinated water at home.

The scientists asked many people to join their study – there were 1085 people in Group 1. The big sample size would help to make the evidence reliable.

The scientists did not collect evidence from people younger than 30. They only wanted to investigate people who had been drinking chlorinated water – or any water at all – for 30 years.

The scientists collected evidence by talking to people in their homes. They asked questions about many things:

- how long they had lived in their home
- their age
- their education
- their income (how much money they earned)
- their health.

The scientists asked the first two questions to check whether a person should be included in the study. They asked about education and income because these two variables affect health, as well as drinking water quality.

The scientists asked many questions about health. They wanted to know if people had had cancer. They asked about waterborne diseases such as cholera, typhoid, and dysentery. They also asked about skin infections and kidney diseases.

Considering evidence

The scientists thought about their evidence. They used their data to do calculations. They made two conclusions:

- Drinking chlorinated water did not significantly increase the chance of cancer.
- Drinking chlorinated water reduced the chance of cholera, typhoid, and dysentery. It also reduced the chance of skin infections and kidney diseases.

Thinking about secondary evidence

The scientists wrote about their work in a scientific journal. They reported exactly what they did, and included their results and calculations.

The large number of people in the study, and the care with which the study was done, mean that other scientists are likely to trust its conclusions.

Q

1. Suggest why the scientists investigating chlorinated water and health in India questioned many people.
2. Suggest why the scientists did not question an even bigger number of people.
3. Suggest why chlorine is added to water supplies where possible, even though chlorine may form trihalomethanes, which may increase the risk of cancer.

!

- Scientists report studies in scientific journals.
- In studies on health, large group sizes help make data reliable.

8.10 Periodic trends

Objectives

- Describe trends in periods of the periodic table
- Describe patterns in data

Groups and periods

Groups

In the periodic table, the vertical columns are called **groups**. The elements in a group have similar properties. There are trends in these properties. For example, in Groups 1, 2, and 7 the melting points of the elements increase going down the group.

Periods

The horizontal rows of the periodic table are called **periods**.

							H										He	⟵ Period 1
Li	Be											B	C	N	O	F	Ne	⟵ Period 2
Na	Mg											Al	Si	P	S	Cl	Ar	⟵ Period 3
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	⟵ Period 4
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	⟵ Period 5
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	⟵ Period 6
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg								

The periodic table shows Periods 1, 2, 3, 4, 5, and 6.

Metal elements are on the left of a period. Non-metal elements are on the right.

Periodic trends

Vipasa asks a scientific question.

Is there a trend in melting points across the periods of the periodic table?

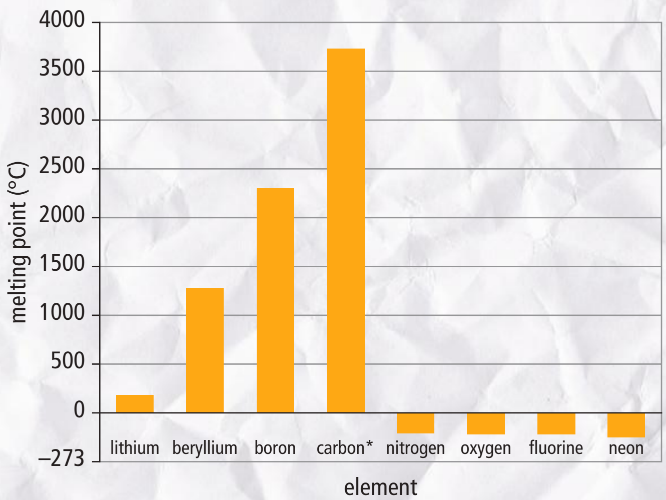
Vipasa decides not to measure the melting points herself. She does not have all the elements she needs, or the equipment to measure their melting points.

Instead, Vipasa collects data from a data book. The data book is the secondary source. Vipasa writes her data in two tables.

Period 2 element	Melting point (°C)
lithium	180
beryllium	1280
boron	2300
carbon	3730 (sublimes)
nitrogen	−210
oxygen	−218
fluorine	−220
neon	−249

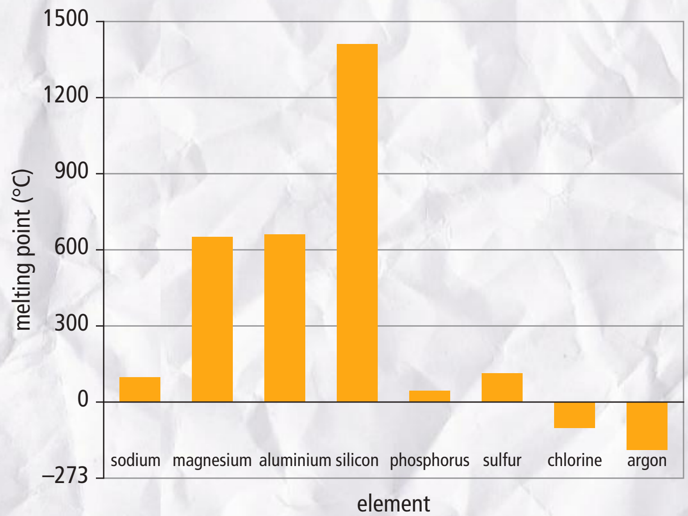
Period 3 element	Melting point (°C)
sodium	98
magnesium	650
aluminium	660
silicon	1410
phosphorus (white)	44
sulfur	113
chlorine	−101
argon	−189

Vipasa cannot see a pattern in her data. She decides to present it on two bar charts. This will make it easier to see if there is a trend in melting points.



* *Note: carbon in the form of graphite sublimes at this temperature.*

The melting points of the Period 2 elements.



The melting points of the Period 3 elements.

Vipasa describes the trends shown on the bar charts. She writes a conclusion.

Trends

- For Period 2, the melting point increases from left to right for the first four elements of the period. The melting points of the other elements are very low.
- For Period 3, the trend is similar.

Conclusion

In every period of the periodic table, the melting point increases from left to right for the first four elements. The melting points of the other elements are very low.

Another student looks at Vipasa's data and conclusion. She says that Vipasa's data supports her conclusion for Periods 2 and 3. But how does she know if the conclusion is true for other periods?

Vipasa decides to collect melting point data for Periods 4 and 5. If the two periods show the same trend, she will be more confident in her conclusion. If they do not show the same trend, she will need to change her conclusion.

Q

1. Name the elements in Period 2 of the periodic table.
2. Explain why Vipasa did not use evidence from first-hand experience to find out about trends in periods.
3. Describe the trend in melting points for Period 3 of the periodic table.

!

From left to right of periods 1 and 2:

- melting points increase for the first four elements
- melting points of the other elements in the periods are lower.

Enquiry 8.11

How scientists work: inside sub-atomic particles

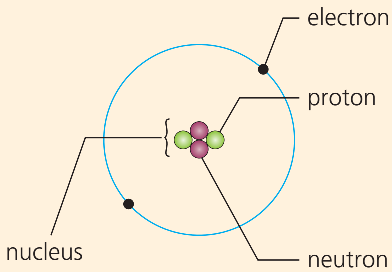
Objective

- Discuss how scientists work today

What's in a proton?

By 1920, scientists knew that most of the mass of an atom is in its nucleus. The nucleus contains protons. Electrons move around an atom, outside its nucleus.

Scientists continued to ask questions. What makes up protons and electrons? Are they made up of even smaller particles?



A helium atom has two protons and two neutrons in its nucleus. Two electrons move around the atom, outside its nucleus.

Suggesting explanations

Scientists used creative thought to suggest explanations. They used maths to support their ideas. Satyendra Nath Bose thought about sub-atomic particles and energy. He wrote to Albert Einstein about his ideas. Together, Bose and Einstein predicted a new state of matter. They called it the Bose-Einstein condensate. The new state would exist only at very low temperatures.

Satyendra Nath Bose was born in Kolkata, India, in 1894.

Other scientists built on the ideas of Bose and Einstein. In 1964, six scientists, including Peter Higgs, suggested an explanation. There is a particle, they said, that gives sub-atomic particle their mass. They called this particle the Higgs boson, in honour of Satyendra Nath Bose.

In Pakistan, Mohammed Abdus Salam used ideas about the Higgs boson to develop explanations about forces between sub-atomic particles.

Archana Sharma of India worked on the Higgs boson team.

Testing the explanation

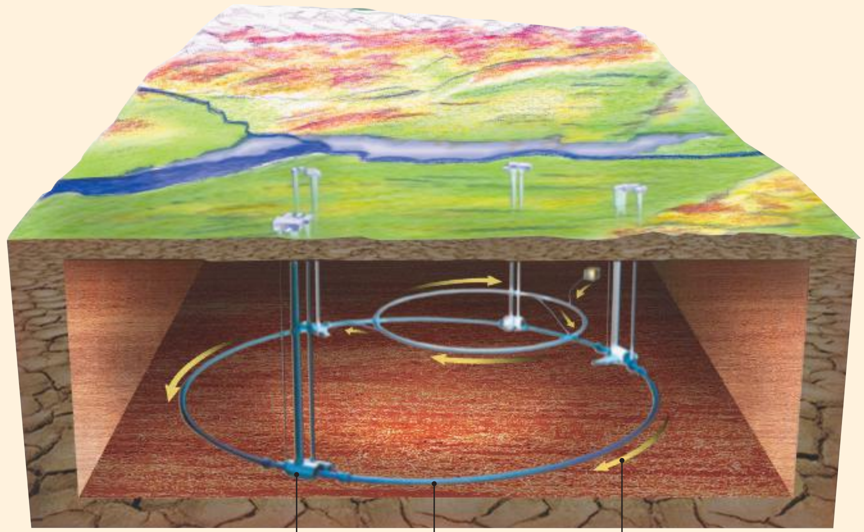
Scientists look for evidence to test explanations. They started looking for the Higgs boson.

In Europe, 10 000 scientists from more than 100 countries worked together. They had one purpose. To design and build apparatus to detect the Higgs boson. The result of their work – the Large Hadron Collider (LHC) – was ready to use by 2010.

The LHC is a 27 km long circular tunnel, deep underground. It produces beams of high energy protons. Inside the tunnel, huge magnets guide the protons around the circle, in both directions.

The protons travel faster and faster. They collide with each other, and break up. Four huge detectors follow the collisions. They detect the particles made in the collisions. Teams of scientists from India made important parts of these detectors.

The detectors send data to computers all over the world. The computers process the data. Scientists in many countries study the evidence. Does the evidence support the explanation? Do Higgs bosons exist, and do they give sub-atomic particles their mass?



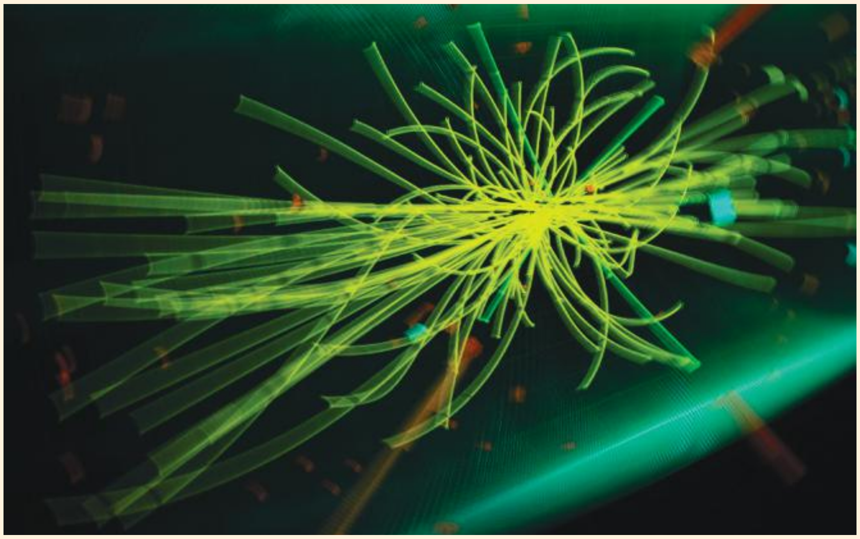
The Large Hadron Collider.

Evidence for the Higgs boson

On 4 July 2012 LHC scientists made an exciting announcement. They had detected a new boson. The boson, they said, behaved as they had predicted a Higgs boson would.

Their evidence supported the explanation put forward nearly 50 years earlier. There is a particle that gives sub-atomic particles their mass. This particle is the Higgs boson.

Of course, scientists cannot be sure that the evidence supports the explanation. They need to spend many more years studying the data that they already have. They also need to do more experiments, to collect more evidence. Will the new evidence support the explanation, or not?



The picture represents two protons colliding.

Q

1. Suggest two advantages of scientists working in international teams.
2. Suggest one disadvantage of working in an international team.
3. Suggest why it easier for scientists to collaborate in international teams today than it was 100 years ago.

!

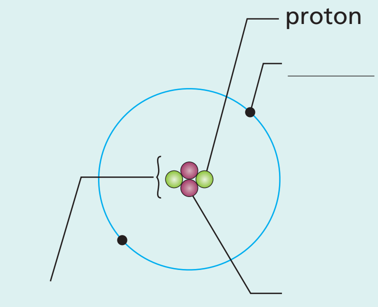
To develop explanations scientists:

- ask questions
- use creative thought to suggest ideas
- collect and consider evidence
- collaborate with each other, often in international teams.

Review 8.12

1 Copy the diagram below and fill in the missing labels. Choose from the words below. Use each word once, more than once, or not at all.

nucleus **proton** **electron** **neutron**



[3]

2 Complete the table to show the relative mass and charge of each sub-atomic particle.

Sub-atomic particle	Charge	Relative mass
proton	+1	
neutron		
electron		$\frac{1}{1840}$

[4]

3 A phosphorus atom is made up of 15 protons, 15 electrons, and 16 neutrons. Explain why it is electrically neutral. [1]

4 Ernest Rutherford fired tiny positively-charged particles at thin gold foil.

a Explain why most of the tiny particles travelled straight through the gold foil. [1]

b Explain why a few tiny particles bounced backwards off the foil. [1]

5 Draw the electronic structures of the following atoms.

a A helium atom, with 2 electrons. [1]

b A sodium atom, with 11 electrons. [1]

c A phosphorus atom, with 15 electrons. [1]

6 The electronic structure of lithium is 2,1.

a Write the electronic structures for sodium and potassium. [1]

b Describe one way in which the electronic structures are similar. [1]

c Describe the link between the atomic structure of an element, and the periodic table group the element is in. [1]

7 The table gives the melting points of four elements in Group 1 of the periodic table.

Element	Melting point (°C)
lithium	180
sodium	98
potassium	64
rubidium	39

a Draw a bar chart to show the melting points of the Group 1 elements. [3]

b Describe the trend in the melting points of Group 1 elements. [1]

8 Katya watches as her teacher adds a small piece of sodium to water. She makes these observations.

The sodium moves around on the surface of the water.
Bubbles are formed.
After the reaction finished, the teacher added Universal Indicator to the solution. The indicator went purple.

a Explain what the bubbles show. [1]

b Explain why the indicator went purple. [1]

c Write a word equation for the reaction of sodium with water. [2]

d Potassium also reacts with water.

i Describe one way in which this reaction is similar to the reaction of sodium with water. [1]

ii Describe one way in which the reaction of potassium with water is different from the reaction of sodium with water. [1]

e Describe the trend in the reactions of the first three Group 1 elements (lithium, sodium, and potassium) with water. [1]

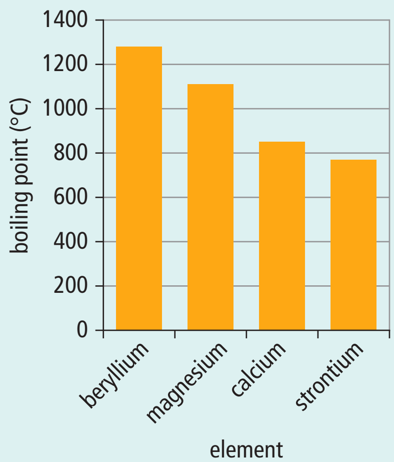
9 The table gives the relative sizes of the atoms of the Group 1 elements.

Element	Relative size of atom
lithium	16
sodium	19
potassium	24

a Describe the trend shown in the table. [1]

b Use ideas about the electronic structures of the elements to suggest a reason for the trend you described in part (a). [1]

10 The bar chart shows the boiling points of four Group 2 elements. Beryllium is at the top of the group, followed by magnesium, calcium, and strontium.



a Describe the trend shown by the bar chart. [1]

b Barium is under strontium in the periodic table. Use the bar chart to predict its boiling point. [1]

c Predict one other trend shown by the Group 2 elements. Give a reason for your prediction. [2]

11 Paulo investigates how vigorously the Group 2 elements react with water. He wants to find out if there is trend in these reactions.

a Name the variable he changes and the variable he observes. [1]

b Identify one variable Paulo should keep constant. [1]

c Suggest what preliminary work Paulo could do before starting his investigation. [1]

d Paulo decides to collect evidence from first-hand experience for the reactions of magnesium and calcium with water. He collects evidence from secondary sources for the reaction of strontium with water. Suggest why he decides not to add strontium to water himself. [1]

12 The Group 7 elements are non-metals.

a Name two elements in Group 7. [2]

b From the list below, choose two properties of the Group 7 elements.

- **do not conduct electricity**
- **good conductors of heat**
- **all have high melting points**
- **all are solid at room temperature**
- **poor conductors of heat**
- **good conductors of electricity.** [2]

c The table gives most of the melting and boiling points of four Group 7 elements.

Element	Melting point (°C)	Boiling point (°C)
fluorine	-220	-118
chlorine		-35
bromine	-7	59
iodine	114	184

i Name the element in Group 7 that is liquid at 20 °C. [1]

ii Describe the trend in boiling points in Group 7. [1]

iii Use the trend in melting points to predict the melting point of chlorine. [1]

d Chlorine has 17 electrons. Its electronic structure is 2,8,7. Draw the electronic structure of chlorine. [3]

13 This question is about the elements in Period 3 of the periodic table.

a The electronic structure of sodium is 2,8,1. Write the electronic structures of the other seven elements in Period 3. [7]

b Name two metals in Period 3. [1]

c Name two elements in Period 3 that do not conduct electricity. [1]

d The table gives the relative size of the atoms of the Period 2 elements. Describe the trend shown in the table. [1]

Element	Relative size
sodium	16
magnesium	14
aluminium	13
silicon	12
phosphorus	11
sulfur	10
chlorine	10

9.1 Energy changes in chemical reactions

Objective

- Explain the difference between exothermic and endothermic reactions

Fuels for cooking

Kemala cooks over kerosene. Wani uses wood. Grace burns gas to heat her food. Kerosene, wood, and gas are **fuels**. Fuels release useful heat when they burn.

Burning reactions release heat. Reactions that release, or give out, heat are called **exothermic reactions**.

Burning wood is an exothermic reaction.

Burning gas is an exothermic reaction.

Melting and evaporation

Some changes take in heat from the surroundings. These are **endothermic** processes.

Imagine a block of ice on your hand. The ice starts to melt. Your hand feels cold. This is because the ice takes heat from your hand. Its particles use this energy to leave their places in the pattern of solid ice, and start moving around, in and out of each other. Melting is endothermic.

Melting is an endothermic process.

Evaporation is endothermic, too. The particles of a liquid take in heat from the surroundings. They use this energy to leave the liquid.

Exothermic or endothermic?

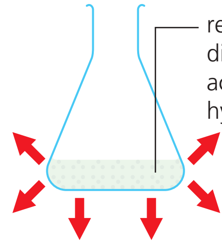
All chemical reactions and changes of state involve energy changes. You can use temperature changes to work out whether a change is exothermic or endothermic.

A neutralisation reaction

Tim pours 50 cm^3 of hydrochloric acid into a plastic cup. He measures its temperature. He adds 50 cm^3 of sodium hydroxide solution. A neutralisation reaction takes place. Tim measures the temperature again.

hydrochloric acid + sodium hydroxide → sodium chloride + water

	Temperature (°C)
hydrochloric acid, before reaction	21
sodium hydroxide, before reaction	21
reaction mixture, immediately after reaction	52
reaction mixture, 1 hour after reaction	21



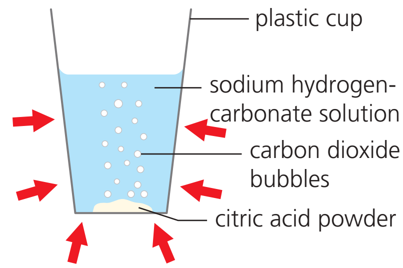
In an exothermic reaction, heat is released to the surroundings. At first, the temperature of the reaction mixture increases.

The reaction releases energy. It is exothermic. At first, the energy that is released heats up the reaction mixture. Then the energy is transferred to the surroundings. The mixture cools to room temperature. Most neutralisation reactions are exothermic.

The reaction of sodium hydrogencarbonate with citric acid

Meg pours sodium hydrogencarbonate solution into a plastic cup. She measures its temperature. She adds citric acid powder. The mixture fizzes, and a reaction takes place. Meg measures the temperature again. The temperature is lower.

During the reaction, the reacting mixture uses heat from the solution. That's why its temperature decreases. Afterwards, the mixture of products takes in heat from the surroundings. The mixture warms to room temperature. The reaction is endothermic.



In an endothermic reaction, heat is taken in from the surroundings. The temperature decreases.

Dissolving – exothermic or endothermic?

Caz dissolves four substances in water. She records the temperature changes in a table.

Substance dissolved	Temperature change (°C)	Exothermic or endothermic?
ammonium chloride	−3	endothermic
potassium nitrate	−9	endothermic
copper sulfate	+7	exothermic
ammonium nitrate	−6	endothermic

The results show that dissolving can be exothermic or endothermic. If the temperature decreases, the reaction is endothermic. The reaction takes in heat.

Q

1. Name two types of reaction that are usually exothermic.
2. Give an example of a change which is endothermic.
3. Name one type of change that can be exothermic or endothermic.
4. Explain why the temperature increases during an exothermic reaction.

!

- Exothermic reactions release, or give out, heat.
- Endothermic reactions take in heat.

Enquiry

9.2 Investigating fuels

Objective

- Consider how to plan an investigation, obtain evidence, and draw conclusions

Planning an investigation

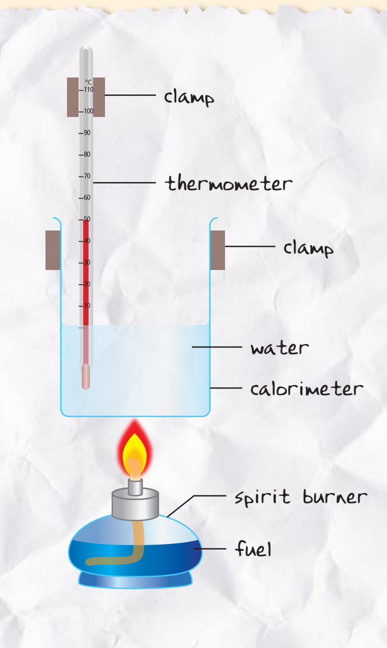
Ideas for testing

Fatima thinks about fuels. She asks herself some questions.

Fatima decides to investigate three fuels. She plans to find out which fuel makes water hottest.

Preliminary work

Fatima sketches her apparatus. She considers the variables in her investigation. She makes some notes.



Variable to change – type of fuel

Variable to measure – temperature change of water

Variables to control – mass of fuel burned, volume of water

Fatima does not know what volume of water to use. She decides to do some preliminary work. She tries heating different volumes of water with 1 g of one of her fuels.

Volume of water (cm^3)	Temperature change (°C)
10	water boiled
100	about 50
1000	about 5

Fatima decides to heat 100 cm^3 of water in her investigation. The temperature change for this volume is likely to be measurably different for each fuel.

Obtaining evidence

Reducing error and increasing reliability

Fatima sets up her apparatus. She thinks about her investigation.

Fatima decides to repeat her investigation three times.

- If the values for temperature increase are similar each time, she will know that her investigation is **reliable**.
- If one temperature increase is very different from the other two, she will check it again. This will reduce error.

Presenting results

Fatima draws a table for her results.

Fuel	Temperature change (°C)			
	first time	second time	third time	average
ethanol	60	40	40	
propanol	50	53	56	53
butanol	55	57	53	55

Fatima looks at the results in her table. She notices that the first result for ethanol is very different from the other two. She thinks she must have made a mistake.

Fatima repeats the test for ethanol again. This time, the temperature change is 43 °C. It is much closer to the other two results for ethanol. By repeating the investigation, Fatima has reduced error and increased the reliability of her results.

Drawing conclusions

Fatima calculates average values for the temperature changes. She writes a conclusion for her investigation.

The temperature change for ethanol was smallest, with an average value of 41 °C. This means that ethanol releases less heat on burning than the other two fuels.

The average value for the temperature change of propanol is 53 °C and for butanol is 55 °C, so propanol and butanol release more heat on burning than ethanol.

Q

1. Explain why Fatima repeated her investigation.
2. Explain how Fatima's results show that ethanol releases less heat on burning than the other two fuels in her investigation.
3. Suggest why Fatima does not investigate the question. *Which fuel is best?*

!

- Repeating measurements in an investigation reduces error and makes results more reliable.
- Temperature change gives an indication of how much heat is released in an exothermic reaction – the greater the temperature change, the more heat is released.

Extension

9.3

Choosing fuels

Objective

- Consider the advantages and disadvantages of vehicle fuels

Tinho lives in Brazil. His car is fuelled by ethanol.

What is a fuel?

Tinho lives in Brazil. His car runs on ethanol. Lorne is Canadian. His car is fuelled by hydrogen. Mila lives in Angola. Her car runs on diesel.

Ethanol, hydrogen, and diesel are **fuels**. A fuel is a substance that releases useful heat when it burns. Burning fuel reactions are exothermic.

Best fuel

Which fuel is best? There is no easy answer. There are many factors to consider when comparing fuels, including:

- How much heat do they release on burning?
- What products are produced when they burn?
- Where – and how – are the fuels produced?
- How convenient are the fuels to use?
- What are the hazards of using the fuels?

How much heat?

The table shows the heat released on burning three fuels.

Fuel	Heat released on burning (kJ/g)
ethanol	29.8
hydrogen	143.0
diesel	45.0

The table shows that 1 g of hydrogen releases more heat on burning than the other fuels in the table. Ethanol releases the least heat.

What are the products of combustion?

The products of combustion are the substances made when a fuel burns. Hydrogen has only one combustion product – water.

hydrogen + oxygen → water

Ethanol is a compound of hydrogen, carbon, and oxygen. It produces carbon dioxide and water on burning. Carbon dioxide is a **greenhouse gas**. In the atmosphere, it causes climate change.

ethanol + oxygen → carbon dioxide and water

Diesel is a mixture of compounds. Most of its compounds are made up of carbon and hydrogen only. When diesel burns, the main products are carbon dioxide and water. Burning diesel also makes small amounts of compounds that are solid at 20 °C. Some of these products may increase the risk of getting cancer, or heart disease.

How are the fuels produced?

Diesel is separated from crude oil. Crude oil was formed over millions of years from dead sea animals. Crude oil is a non-renewable resource. We are using crude oil much faster than it can be replaced.

Most hydrogen fuel is made from methane. Methane is formed from animal waste, and on rubbish dumps. Methane from these sources is renewable.

Most ethanol fuel is made from plants, such as sugar cane. This means that ethanol is renewable. However, the plants are grown on land that could be used to grow food. The top eight ethanol fuel-producing countries and regions in 2009 were USA, Brazil, the European Union, China, Thailand, Canada, India, and Colombia.

Much ethanol fuel is produced from sugar cane.

Convenience and safety

Diesel and ethanol are liquid at 20 °C. They are convenient to transport and store. Hydrogen is a gas at 20 °C. It is more difficult to store and transport. Mixtures of hydrogen and air are explosive. Hydrogen must be stored away from flames and sparks.

Which fuel is best?

There is no single right answer to this question. Different people – and organisations – will make different decisions depending on the factors that are most important to them.

A hydrogen filling station.

Q

1. What is a fuel?
2. Name the products of combustion of hydrogen, and of ethanol.
3. Draw a table to compare the advantages and disadvantages of three fuels – ethanol, hydrogen, and diesel.

!

- There are many factors to consider when choosing fuels.

Extension
9.4 Calculating food energy

Objective
- Describe how to measure the heat released when food burns

Cashew nuts

Nut energy

Nku buys some cashew nuts. How much energy will they provide? He uses the Internet to find out, and makes some notes. You can find out more about the energy in food in your *Complete Biology for Cambridge Secondary 1* Student Book.

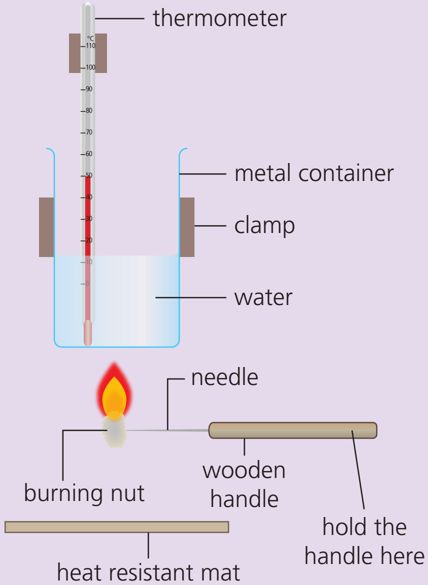
Eating 100 g of cashew nuts provides 2200 kJ of energy.

Nku wants to check this piece of data. He decides to do an experiment.

Measuring the energy in food

Planning investigative work

Nku sets up the apparatus below. He will burn a 1 g piece of cashew. The burning cashew will heat the water. Nku will measure the temperature increase of the water.



Apparatus to measure the energy released as heat when food burns.

Obtaining and presenting evidence

Nku decides to repeat his test three times. This will help to reduce error, and make his results more reliable. He writes a table for his results.

Test number	Water temperature before heating (°C)	Water temperature after heating (°C)	Water temperature change (°C)
1	21	61	40
2	22	65	43
3	22	59	37

Nku looks at his data. The water temperature change was similar for each test. This shows that the results are reliable.

Nku calculates the mean (average) value for the water temperature change:

$$\text{mean temperature change} = \frac{40 + 43 + 37}{3}\ °C$$
$$= 40\ °C$$

Considering evidence

The greater the temperature increase of the water, the more energy a food or fuel has released as heat. But temperature is not the same as heat. Nku needs to do a calculation to find out the amount of heat the cashew released.

The equation for the energy transferred to the water as heat is:

$H = m \times c \times \Delta T$

In the equation:

- $\boldsymbol{H}$ is the energy transferred to the water as heat
- $\boldsymbol{m}$ is the mass of the water
- $\boldsymbol{c}$ is the specific heat capacity of the water, 4.2 J/g °C
- $\Delta \boldsymbol{T}$ is the temperature change of the water

Nku does his calculation. The answer gives the energy transferred as heat by 1 g of burning cashew.

$$H = m \times c \times \Delta T$$
$$H = 100\ g \times 4.2\ J/g\ °C \times 40\ °C$$
$$H = 16800\ J$$
$$H = 16.8\ kJ$$

This gives a value of 1680 kJ for burning 100 g of cashew nuts. Nku compares his result to the value he found on the Internet. His value is lower.

Nku thinks about the two values, and discusses them with his teacher. He writes an evaluation.

My value is less than the value given on the Internet. I trust the data from the Internet site. I think my value was lower because not all the heat from the burning cashew was transferred to the water. Some was transferred to the surroundings and to the apparatus.

Nku decides to continue his investigation. He burns other foods, and uses the heat released to heat water.

Q

1 A mass of 1 g of a burning food heats 100 g of water from 20 °C to 80 °C. Calculate the heat transferred to the water.

2 Explain why the value you calculated in question 1 might be less than the heat released on burning the food.

3 Explain the difference between temperature and heat.

!

- Use the equation $H = m \times c \times \Delta T$ to calculate the heat transferred to water.

Enquiry 9.5

Investigating endothermic changes

Objective

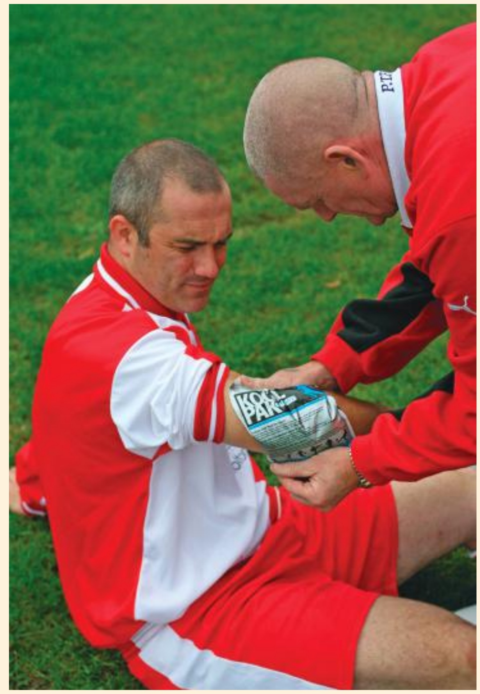
- Plan how to investigate an endothermic process

Dissolving ammonium nitrate

When ammonium nitrate dissolves in water, it takes in heat from the surroundings. The process is endothermic.

A teacher places a drop of water on a block of wood. She places a conical flask on the drop of water. She pours water into the conical flask, and dissolves ammonium nitrate in this water. The dissolving mixture takes heat energy from the drop of water on the wood. The drop of water becomes ice. The ice sticks the block of wood to the flask.

Dissolving ammonium nitrate in water is an endothermic process.



Sports injury packs cool damage muscles. They take in energy from muscles when the solid inside the packs dissolves in water.

Scientific enquiry

Asking questions

Jaka, Kali, and Legi investigate endothermic dissolving processes. They ask some questions.

Jaka

Kali

Legi

Planning investigative work – variables

The students list the variables in their investigation:

- substance used as solute (a solute is the substance that dissolves)
- mass of solute
- volume of water
- temperature change (the greater the temperature change, the greater the amount of heat taken in).

The students decide to investigate Jaka's question. The variable they change is the mass of substance. The variable they measure is the temperature change. The students will keep the other variables constant:

- the solute is ammonium chloride
- the volume of water – they will need to choose a suitable volume.

They do some preliminary work and decide to use 100 cm^3 of water. This volume gives a suitable temperature change between 1 g and 15 g of ammonium chloride.

Planning investigative work – choosing equipment

The students use a balance to measure masses of ammonium chloride. They choose a balance that measures small differences in mass.

They use a thermometer to measure temperature change. They choose a thermometer than measures 0.5 °C changes in temperature.

Planning investigative work – assessing hazards and controlling risk

The students use a secondary source to find out about the hazards of using ammonium chloride. The solid is harmful. They wear eye protection during their experiment.

Obtaining and considering evidence

The students collect their evidence. They repeat their measurements three times to reduce error and make their results more reliable.

They look for a pattern in their results. Then they make a conclusion. The conclusion describes the pattern linking the variable they changed (the mass of ammonium chloride) and the variable they measured (the temperature change).

The students choose a balance that measures small differences in mass. This balance gives the mass to the nearest 0.1 g.

Q

1 Some students investigate Kali's question. Identify the variables they should change, measure, and control.

2 Some students investigate Legi's question.

a Suggest what preliminary work they need to do.

b Draw a table for their results. Include column headings.

!

Planning an investigation may involve:

- identifying variables
- doing preliminary work
- choosing equipment
- assessing hazards and controlling risk.

Review 9.6

1 Choose words and phrases from the list to copy and complete the sentences below. You may use each word or phrase once, more than once, or not at all.

given out **taken in** **increases**
decreases **stays the same**

In an exothermic reaction, heat is ________. The temperature ________. In an endothermic reaction, heat is ________. The temperature ________. [4]

2 Tick a copy of the table to show which changes are exothermic and which changes are endothermic.

Type of change	Is the change exothermic?	Is the change endothermic?
combustion (burning)		
neutralisation		
evaporation		
melting		
freezing		

[5]

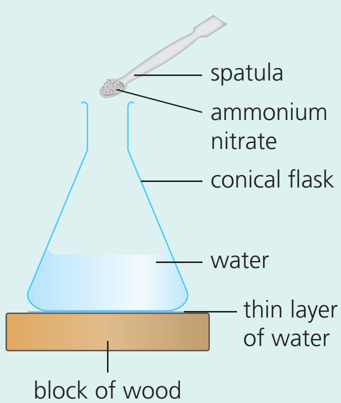
3 The table gives the temperature changes when different substances dissolve in water. The same mass of solid was used in each test, and the same volume of water.

Substance	Temperature change (°C)
ammonium chloride	−5
ammonium nitrate	−6
copper sulfate	+5
potassium nitrate	−9

a Identify the substances that release (give out) heat when they dissolve in water. [1]

b Identify the substance that takes in the most heat when it dissolves in water. [1]

4 Mr Mushi sets up the apparatus below.



He adds ammonium nitrate to the water, and stirs until it dissolves.

a The water between the flask and the wooden block freezes. Explain why. [1]

b Does ammonium nitrate dissolve exothermically or endothermically? Explain how you know. [2]

5 Zoza investigates a neutralisation reaction. She adds 50 cm^3 potassium hydroxide solution to 50 cm^3 of nitric acid. Her results are in the table below.

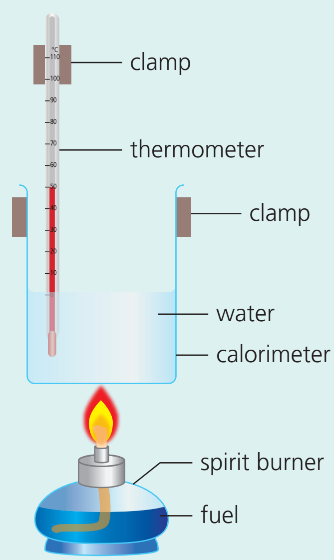
	Temperature (°C)
potassium hydroxide, before reaction	23
nitric acid, before reaction	23
reaction mixture, immediately after reaction	56
reaction mixture, two hours after reaction	23

a Use data from the table to calculate the temperature change during the reaction. [1]

b Explain how the data show that the neutralisation reaction is exothermic. [2]

6 Josie investigates four fuels. She sets up the apparatus below. She uses the fuels to heat water.

She measures the temperature change of the water when she burns different fuels in the spirit burner.



a Identify the variable Josie changes. [1]

b Identify the variable Josie measures. [1]

c Josie heats the same volume of water with each fuel. Name two other variables that Josie should control. [2]

d Josie does some preliminary work to help her decide what volume of water to heat with the fuels. Suggest why. [1]

e Josie's results are in the table.

fuel	temperature at start (°C)	temperature at end (°C)	temperature change (°C)
ethanol	19	56	37
propanol		63	43
butanol	20	65	
pentanol	21	68	47

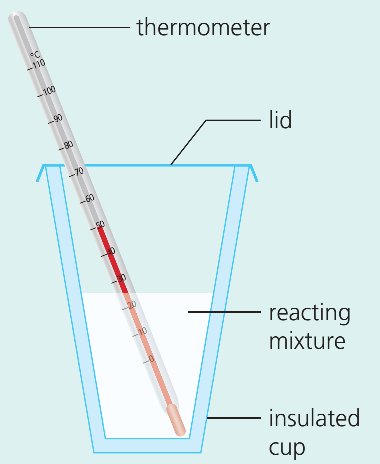
i Copy and complete the table. [2]

ii Which fuel released least energy on burning? [1]

f Josie decided to repeat her investigation. Suggest why. [1]

g Josie thinks that some of the heat released by the burning fuels was not transferred to the water. Where else might the heat have been transferred to? [1]

7 Ashok compares the heat released in different neutralisation reactions. He uses the apparatus below.



Ashok repeats his investigation three times. The table below summarises his results.

Reactants	Temperature change (°C)			
	First time	Second time	Third time	Average
nitric acid and sodium hydroxide	50	32	32	32
hydrochloric acid and potassium hydroxide	34	33	35	34
sulfuric acid and sodium hydroxide	30	34	32	32
sulfuric acid and potassium hydroxide	33	33	33	33

a Suggest why Ashok repeated his investigation three times. [1]

b Ashok ignored his first result for the first pair of reagents. Suggest why. [1]

c Use the data to write a conclusion for the investigation. [1]

10.1 The reactions of metals with oxygen

Objective

- Investigate the burning reactions of metals

Burning metals

Ships and sailing boats often carry flares on board. They use these to attract the attention of the emergency services if they are in distress. When lit, flares emit a bright white or red light that can be seen for miles.

Some flares contain magnesium. Magnesium burns in air. It reacts with oxygen to make magnesium oxide. Once the reaction starts, it is fast and furious. The word equation below summarises the reaction:

magnesium + oxygen → magnesium oxide

Burning magnesium ribbon.

Burning metals in the laboratory

Martha burns a small piece of magnesium ribbon. She sees a bright, white flame. She shields her eyes and does not look at the flame directly, since it will damage her eyes.

Next, Martha sprinkles tiny pieces of iron (iron filings) in a flame. She sees bright sparks. Then she tries burning an iron nail. Nothing happens.

Martha's teacher burns a piece of sodium metal. The flame is very bright, and the reaction very fast.

Burning iron filings.

Burning sodium.

Comparing burning reactions

Planning an investigation

Martha wants to investigate burning metals in more detail. She wants to compare how vigorously they react.

Martha has already observed some metals burning. This is her **preliminary work**. She will use this to help plan her investigation. She writes down some ideas.

> Iron filings burn vigorously. An iron nail does not burn. The size of the metal pieces is important. To make my investigation fair, I will need to control this variable.
>
> My preliminary work shows that big pieces of some metals do not burn. I will compare the burning reactions of tiny pieces of metal.

Making observations and presenting results

Martha decides to sprinkle tiny metal pieces into a hot flame. She plans to observe how vigorously they react.
Martha uses secondary sources to collect data about hazards. She decides not to use sodium – the risks are too great. She asks her teacher to do the magnesium reaction in a fume cupboard.

Martha draws a table. She sprinkles the metals in the flame. She writes down her observations.

Metal	Observations
magnesium	Bright white sparks. Crackling sounds. Very vigorous.
zinc	Bright white sparks. More vigorous than iron?
copper	No signs of a reaction.
iron	Burned – bright yellow sparks.

Interpreting results

Martha describes the pattern in her results, and writes a conclusion.

From my results, I conclude that magnesium reacts most vigorously with oxygen. Next is zinc, then iron. Copper does not react at all.

Martha thinks about her investigation. It was difficult to judge whether zinc or iron reacted more vigorously. She cannot be sure that her order is correct. She writes the comment below.

Evaluation:

From my investigation, I cannot be sure that the order is correct. I need to do another investigation to collect more evidence.

Martha also realises that she has not used scientific knowledge to explain her results. She plans to use secondary sources to find out why magnesium reacts more vigorously than the other metals she tested.

Q

1. Describe two signs that show that a chemical reaction happens when magnesium burns in air.
2. Name the product formed when iron burns in air.
3. Write a word equation for the burning reaction of zinc in air.
4. List these three metals in order of how vigorous their reactions with oxygen are, most vigorous reaction first: iron, magnesium, copper.

!

- Some metals burn in air.
- On burning, metals react with oxygen to make metal oxides.
- The burning reactions of sodium and magnesium are very vigorous.

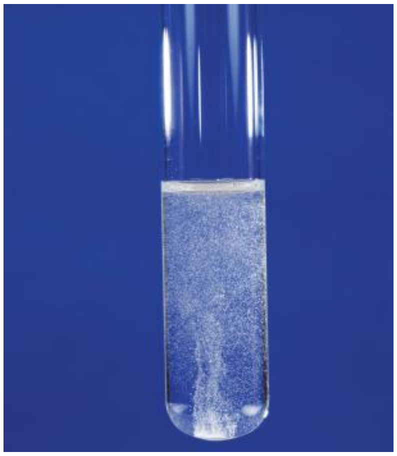
10.2 The reactions of metals with water

Objective

- Describe how metals react with water

Calcium and water

Do metals react with water? Not the ones we use most often. There would be a problem if metal taps reacted with water, or if metal cars reacted with rain.



Calcium reacts vigorously with water.

But some metals do react with water. Winton drops a small piece of calcium into a beaker of water. It bubbles quickly. After a while, the bubbling stops. The piece of calcium seems to have disappeared.

The calcium has reacted with the water. The bubbles contained hydrogen gas. The equation below shows the reactants and products:

calcium + water → calcium hydroxide + hydrogen

Even more exciting reactions

Lithium reacts with water very vigorously.

Calcium is not the only metal that reacts with water. Other metals have even more vigorous reactions.

Lithium whizzes around on the surface of a big bowl of water. It makes bubbles of hydrogen gas, like calcium. The other product is lithium hydroxide.

lithium + water → lithium hydroxide + hydrogen

On page 157 we learned that sodium and potassium react with water more vigorously than lithium. Potassium gets so hot that it sets fire to the hydrogen made in the reaction.

Not all metals react with water…

Magnesium ribbon reacts with cold water. The reaction is so slow that you hardly notice it. Zinc does not react with cold water, but it does react with steam.

23 December 2007

Yesterday, Chinese archaeologists raised the wreck of an 800-year-old ship from the depths of the South China Sea. The ship, which sank in heavy storms, was carrying exquisite treasures to sell overseas. The treasure includes gold, silver, and tin pots, and 6000 copper coins. There's even a sailor's gold belt buckle and silver rings.

Why did the treasure survive under the sea for so long? It's because gold, silver, copper, and tin do not react with cold water.

Metals that do not react with water are very useful. Copper makes excellent water pipes. Gold and silver rings are very attractive, and you can't damage them by washing your hands.

This gold fan was found in Egypt. It is 3300 years old. It has not reacted with water, so it is still shiny.

An order of reactivity

The table below summarises how vigorously some metals react with water.

Metals	Comment	
potassium sodium lithium calcium	most vigorous reactions	reactions get less vigorous ↓
magnesium zinc		
copper silver gold platinum	do not react with water under normal conditions	

All the metals that react with water form two products:

- an oxide or hydroxide
- hydrogen.

The metals that react vigorously with oxygen also react vigorously with water. Is there a similar pattern for the reactions of metals with acids? Turn over to find out.

Q

1. Name three metals which react vigorously with water.
2. Name the products of the reaction when potassium reacts with water. Write a word equation for the reaction.
3. Explain why gold coins stay shiny for hundreds of years.

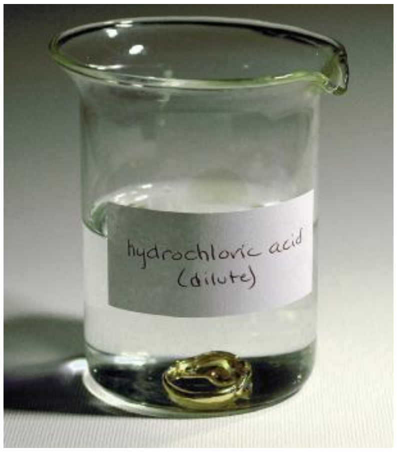
!

- Some metals react with water to make hydrogen and a metal oxide or hydroxide.
- Potassium, sodium, lithium, and calcium react most vigorously with water.
- Gold, silver, and copper do not react with cold water.

10.3 The reactions of metals with acids

Objective

- Describe how metals react with acids



Ring reaction?

Sundara has a ring. It is an alloy of three metals – gold, silver, and copper. Sundara drops her ring in dilute hydrochloric acid. Nothing happens. She rinses the ring and puts it back on her finger. The ring survives because its metals do not react with dilute acids.

Investigating acid reactions

Many metals do react with acids. Dan wants to investigate which metals react most vigorously. His teacher gives him small pieces of five metals.

Assessing hazards and controlling risks

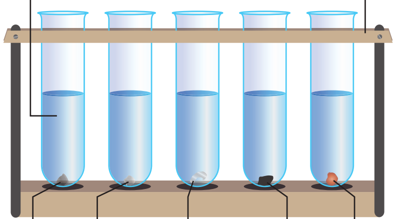
Dan assesses the hazards of the substances he will use. He writes down how to control the risks from the hazards.

Substance	Hazard	How to control risks from hazard
dilute hydrochloric acid	Low hazard, but may cause harm in eyes or cuts.	Wear eye protection, and take care not to spill on skin.
hydrogen (made in reactions)	Makes explosive mixtures with air.	Make small quantities. Do not use bung in test tube.
iron	Low hazard.	
zinc	Low hazard.	
magnesium	Catches fire easily.	Keep away from flames.
lead	Low hazard, harmful if swallowed.	Wash hands after use.
copper	Low hazard.	

Obtaining evidence

Dan sets up the apparatus below. To make the test fair, he controls these variables:

- concentration of hydrochloric acid
- size of metal pieces.



Reacting metals with dilute hydrochloric acid.

Testing for hydrogen

Magnesium bubbles vigorously with hydrochloric acid. Dan collects the gas by placing another test tube over the top of the first one.

Dan lights a splint. Keeping the test tube containing the hydrogen upside down, he quickly places the lighted splint in to the test tube. The splint makes a squeaky pop, and goes out. This shows that the reaction makes hydrogen gas.

In hydrogen gas, a lighted splint goes out with a squeaky pop.

Considering evidence

Dan lists the metals in order of how vigorously they react.

Metal	Comment	
magnesium	vigorous reaction	reactions get less vigorous ↓
zinc		
iron		
copper	did not react	

In Dan's experiment, the piece of magnesium gets smaller. It disappears. Only a colourless solution remains in the test tube.

The magnesium and hydrochloric acid have reacted to make hydrogen gas and magnesium chloride. The hydrogen gas leaves the test tubes in bubbles. The magnesium chloride dissolves in water, so you cannot see it. This word equation summarises the reaction:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

Magnesium chloride is a salt. A salt is a compound made when a metal replaces the hydrogen in an acid.

Every metal that reacts with hydrochloric acid makes a salt and hydrogen gas. The equations for the reactions in Dan's experiment are given below.

zinc + hydrochloric acid → zinc chloride + hydrogen

iron + hydrochloric acid → iron chloride + hydrogen

Look back at pages 182–5. Can you see any similarities in how vigorously the metals react with oxygen, water, and hydrochloric acid?

Q

1. Name two metals that react vigorously with dilute acid.
2. Name the products of the reaction when magnesium reacts with dilute acid and write a word equation for the reaction.
3. Describe the test for hydrogen gas. Write down what you would see and hear if hydrogen gas is present.
4. Explain why, in his investigation, Dan used pieces of metal of the same size.

!

- Many metals react with dilute acids to make salts and hydrogen gas.
- Magnesium and zinc react vigorously with dilute acids.
- Copper and gold do not react with dilute acids.

10.4 The reactivity series

Objective

- To understand the reactivity series

A pattern of reactions

The pattern of metal reactions with acids is similar to their pattern of reactions with water, and with oxygen.

Potassium, sodium, and lithium react vigorously with water and oxygen, and violently with dilute acids. Calcium and magnesium have the next most vigorous reactions.

Sodium reacts vigorously with water. The indicator phenolphthalein has been added to this water. The indicator turns pink when it detects sodium hydroxide, the alkaline product of the reaction.

Zinc, iron, and lead react slowly (or not at all) with dilute acids and cold water. They burn in air, but their reactions are less vigorous than those of magnesium.

Silver, gold, and platinum do not react with water, dilute acids, or oxygen at normal conditions.

The **reactivity series** describes this pattern of metal reactions. It lists the metals in order of how vigorously they react. The metals at the top have very vigorous reactions. They are the most reactive. Going down the reactivity series, the metals get gradually less reactive. The metals are the bottom are unreactive.

potassium
sodium
lithium
calcium
magnesium
aluminium
zinc
iron
lead
copper
silver

The reactivity series of metals.

The reactivity series and the periodic table

The metals at the top of the reactivity series are in Groups 1 and 2 of the periodic table. Most of the unreactive metals are transition metals, in the middle of the periodic table.

1	2	transition elements										3	4	5	6	7	0
							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Groups 1 and 2

The metals at the top of the reactivity series are in Groups 1 and 2 of the periodic table.

Using the reactivity series

Predicting corrosion

Metals near the top of the reactivity series burn vigorously in air when they are heated. They react with oxygen to form oxides. For example:

lithium + oxygen → lithium oxide

Metals at the top of the reactivity series react with oxygen at normal temperatures, too. Lithium is shiny when freshly cut. In air, a dull white substance forms quickly on its surface. The white substance is lithium oxide. It forms when surface lithium atoms react with oxygen.

The reaction of surface atoms of a metal with oxygen, or other substances, is called **corrosion**. Metals at the top of the reactivity series corrode easily. Metals at the bottom of the reactivity series do not corrode.

Lithium corrodes quickly in air. The shiny surface has been freshly cut. It will soon go grey, like the rest of the surface of the metal.

Preventing corrosion

Samindee's dad is buying a boat. Should he buy one made from aluminium, or steel? Steel is mainly iron.

Which corrodes quicker – steel, or aluminium?

Samindee sees that aluminium is above iron in the reactivity series. She predicts that aluminium will corrode more quickly. But this is not the case.

Freshly-cut aluminium immediately reacts with oxygen from the air. A thin, hard aluminium oxide coating forms. This stops water and oxygen molecules hitting the aluminium atoms below. The aluminium cannot react. It is protected from corrosion.

Steel corrodes more easily. Its iron atoms react with water and oxygen molecules to make hydrated iron oxide. This is red-brown rust, which flakes off. Holes may form and let water in.

It is vital to protect steel boats. Paint offers good protection, except when scratched. Many steel boats have a piece of zinc attached to them. Zinc is more reactive than iron. It reacts with water and oxygen instead of iron. The zinc is sacrificed to save the iron, so this is called **sacrificial protection**.

Zinc is bolted onto the boat's hull. It corrodes instead of the steel.

Q

1. Use the reactivity series to name two metals that are more reactive than magnesium, and three metals that are less reactive.
2. Predict what would happen if a scientist added potassium to a dilute acid.
3. Zinc protects steel boats by sacrificial protection. Explain why magnesium also protects boats in this way.

!

- The reactivity series is a list of metals in order of how vigorous their reactions are.

Enquiry

10.5

Nickel in the reactivity series

Objective

- Plan an enquiry and interpret evidence to work out the position of nickel in the reactivity series

Asking questions

Priti wears a watch with a metal strap. It makes her wrist go red and itchy. The watchstrap includes nickel. Priti is allergic to this metal.

Priti wonders about the properties of nickel. She decides to investigate. She asks a question.

Planning an investigation

Priti knows that the reactions of a metal with oxygen, water, and dilute acids show the position of a metal in the reactivity series.

First, Priti does some research on the Internet and finds out that the salts formed by reaction of nickel with acids can be toxic. She decides to use evidence from secondary sources.

Priti collects evidence from secondary sources to compare the reaction of nickel with acid to the reactions of other metals. She writes her findings in a table.

metal	observations on adding to dilute acid
nickel	bubbles form slowly
magnesium	bubbles vigorously
zinc	bubbles vigorously
copper	no reaction

Priti thinks about her findings so far. She concludes that nickel must be between zinc and copper in the reactivity series. She decides to compare the reactions of nickel to two other metals in this part of the reactivity series – iron and lead.

potassium
sodium
lithium
calcium
magnesium
aluminium
zinc
iron
lead
copper
silver
gold

The reactivity series.

Obtaining evidence

Priti assesses the hazards of the metals she plans to use – nickel, iron, and lead. Then she starts collecting evidence.

Priti judges that the hazards of burning powdered nickel, iron, and lead are too great. She also uses secondary sources to find out about these reactions.

Metal	Reaction of powdered metal with air
nickel	reacts quickly to make nickel oxide
iron	reacts quickly to make iron oxide
lead	reacts quickly to make lead oxide

Next, Priti adds samples of the metals to water. A week later, she notes her observations.

Metal	Observations after leaving the metal in water and air for one week
nickel	no reaction
iron	red-brown flaky substance formed
lead	no reaction

Finally, Priti adds pieces of iron and lead to dilute sulfuric acid. She writes down her observations.

Metal	Observations on adding to dilute sulfuric acid	Notes
nickel	slowly, bubbles form	evidence from a secondary source (text book)
iron	bubbles form, more vigorous than reaction of nickel	evidence from first-hand experience
lead	no reaction	evidence from first hand experience

Considering the evidence

Priti studies the evidence. She uses her knowledge and understanding to interpret the results. She writes a conclusion.

The reactions of the metals with water show that nickel may be less reactive than iron. The reactions of the metals with dilute sulfuric acid support this conclusion.

The reactions of the metals with dilute sulfuric acid show that nickel may be higher in the reactivity series than lead. However, I need more evidence to be confident in this conclusion.

On the basis of the evidence I have, nickel is between iron and lead in the reactivity series.

Q

1 Explain why Priti collected most of her evidence from secondary sources.

2 Explain why the reactions of oxygen with iron, nickel, and lead did not help Priti to find the position of nickel in the reactivity series.

3 Suggest why Priti wants more evidence to be confident that nickel is higher in the reactivity series than lead.

!

- You can compare the reactions of metals to find their positions in the reactivity series.

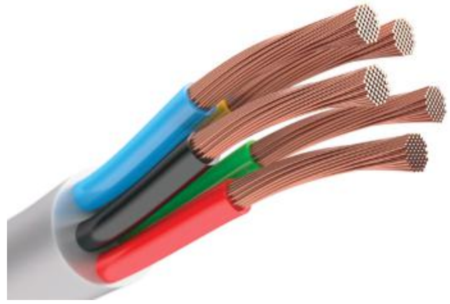
10.6 Metal displacement reactions

Objective

- Explain what displacement reactions are, and how they are useful

Copper – a vital metal

Copper is an important metal. Its properties make it perfect for electrical equipment, water pipes, and heat exchangers. Worldwide, we produce about 15 million tonnes of the metal each year. In 2009 Indonesia alone produced nearly 1 million tonnes of copper.



About 60% of copper is used to make electrical equipment.

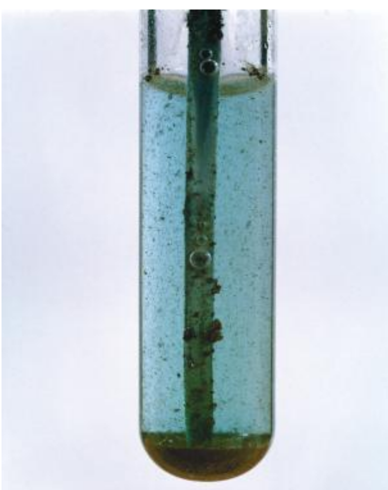
World reserves of copper will not last forever. This is why we recycle copper. Companies also extract copper from copper ore waste. This is how they do it:

- Spray dilute sulfuric acid onto copper ore waste. This makes copper sulfate solution.
- Add waste iron to the copper sulfate solution. The products of the reaction are copper and iron sulfate.

The equation below shows the reaction of iron with copper sulfate solution:

iron + copper sulfate → copper + iron sulfate

This is an example of a **displacement reaction**. Iron is more reactive than copper. It has **displaced** – or pushed out – copper from its compound.



Iron is more reactive than copper. The iron is displacing copper from copper sulfate solution. Copper is being formed.

More displacement reactions in solution

A more reactive metal will displace a less reactive metal from its compounds in solution.

Mandeep adds magnesium to blue copper sulfate solution. In a few minutes, she notices copper metal in the test tube. The blue solution becomes paler.

There has been a displacement reaction. Magnesium is higher in the reactivity series than copper. It displaces copper from copper sulfate solution.

magnesium + copper sulfate → copper + magnesium sulfate

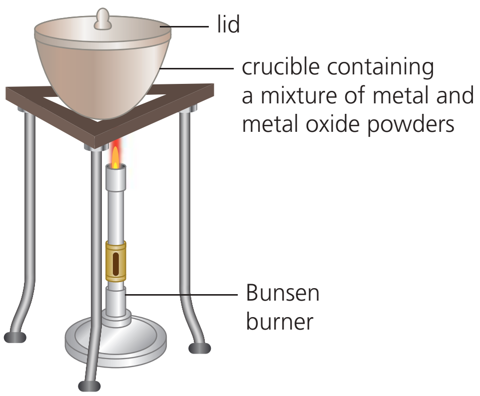
Mandeesha adds copper to magnesium chloride solution. Nothing happens. There is no reaction, because copper is less reactive than magnesium. Copper cannot displace magnesium from its compounds.

Displacing metals from metal oxides

Alex wonders if metals displace other metals from their oxides. He uses science knowledge to make a prediction.

I predict that a more reactive metal will displace a less reactive metal from its oxide.

Alex plans to heat pairs of substances. He will look for signs of reaction, and observe any products made. He draws a table for his results.



Alex heats a mixture of a metal and a metal oxide.

Metal element	Metal oxide	Observations
iron	copper oxide	glows red, pink-brown metal formed
copper	iron oxide	no reaction
zinc	copper oxide	glows red, pink-brown metal formed
copper	zinc oxide	no reaction
zinc	iron oxide	glows red, silver-coloured metal formed

Alex looks for patterns in his results. If the metal element is more reactive than the metal in the oxide, there is a reaction. He writes a conclusion.

A more reactive metal displaces a less reactive metal from its oxide.

iron + copper oxide → copper + iron oxide

zinc + copper oxide → copper + zinc oxide

zinc + iron oxide → iron + zinc oxide

The thermite reaction

Aluminium is more reactive than iron. Aluminium reacts with iron oxide. The products are iron and aluminium oxide. Aluminium displaces iron from its oxide. This is the **thermite reaction**:

aluminium + iron oxide → aluminium oxide + iron

The thermite reaction gives out lots of heat. The heat melts the iron. Railway workers use liquid iron from the thermite reaction to join rails together.

The thermite reaction.

Liquid iron from the thermite reaction joins rails together.

Q

1. What is a displacement reaction?
2. Decide which of these pairs of reactants react, and write word equations for the reactions: magnesium and copper oxide; zinc and magnesium oxide; zinc and copper sulfate solution.
3. Describe one displacement reaction that is useful, and explain why it is useful.

!

- More reactive metals displace less reactive metals from solutions of their salts, and from their oxides.

10.7 Using the reactivity series: extracting metals from their ores

Objective

- Explain the link between the position of a metal in the reactivity series, and how the metal is extracted from its ore

Metal compounds and the reactivity series

The higher a metal in the reactivity series, the more strongly its atoms are joined to atoms of other elements in compounds.

The more strongly the atoms of a compound are joined, the more difficult it is to extract an element from the compound.

Extracting gold

Gold is unreactive. It is found as an element in the Earth's crust. The metal is easily separated from the substances it is mixed with.

Some gold is found in stream beds, mixed with sand and gravel. You can separate gold by placing the mixture in a pan, and adding water. Gold is more dense than sand and gravel. It sinks to the bottom of the pan.

Panning for gold.

Extracting metals in the middle of the reactivity series

Iron

Most metals are not found as elements in the Earth's crust. They are joined to other elements in compounds. The compounds must be broken down to get metals out of them.

Iron is a vital metal. It is in nearly all the metal objects we use. Most iron exists as oxides in the Earth's crust. The oxides are heated with carbon. Carbon is more reactive than iron. It removes oxygen from iron oxide.

This ship is made from steel. Steel is mainly iron.

Lead

People have used lead for up to 8000 years. Lead beads were made in Turkey in about 6400 BCE. Skilled craftspeople made lead objects in the Indus valley about 4000 years ago.

Lead exists as lead sulfide in the Earth's crust. Lead is extracted like this:

- Heat lead sulfide in air:
  lead sulfide + oxygen → lead oxide + sulfur dioxide
- Heat the lead oxide with carbon. Carbon is more reactive than lead. It removes oxygen from lead oxide:
  lead oxide + carbon → lead + carbon dioxide

This lead statuette was made in Greece over 3000 years ago.

A pattern of reactions

Zinc, and metals below zinc in the reactivity series, can be extracted from their oxides by heating with carbon. The reactions work because carbon is more reactive than these metals.

Carbon is chosen because it is cheap, and there is plenty of it. It is possible to extract iron from iron oxide by heating with a more reactive metal, like magnesium. But magnesium is rarer than iron. It is much more expensive.

Extracting metals at the top of the reactivity series

Aluminium is near the top of the reactivity series. In the Earth's crust, it exists as aluminium oxide. The aluminium and oxygen atoms are strongly joined together. Carbon is not reactive enough to remove oxygen from aluminium oxide.

Aluminium is extracted from its oxide by **electrolysis**:

- Dissolve pure aluminium oxide in a special solvent.
- Pass a 100 000 amp electric current through the solution. The electricity splits up aluminium oxide. Liquid aluminium is produced.

Other reactive metals are also extracted from their compounds by electrolysis. Sodium is extracted by passing an electric current through seawater.

Aluminium is near the top of the reactivity series. An electric current separates the metal from its oxide.

Q

1. Name two elements that are extracted from their compounds by electrolysis.
2. Explain why iron is extracted from its ore by heating with carbon.
3. Describe the link between the position of a metal in the reactivity series, and how the metal is extracted from its ore.

!

- Metals near the top of the reactivity series are extracted from their compounds by electrolysis.
- Metals below aluminium are extracted from their oxides by heating with carbon.

Extension

10.8 Writing symbol equations

Objective

- Write balanced symbol equations for simple reactions

Why write symbol equations?

Word equations summarise chemical reactions. They show the reactants and products.

A balanced symbol equation tells us more about a reaction. It shows:

- the formulae of the reactants and products
- how the atoms are rearranged in the reaction
- the relative amounts of reactants and products.

How to write a symbol equation

Zinc and copper oxide

Zinc reacts with copper oxide in a displacement reaction. The products are copper and zinc oxide.

Follow the steps below to write a balanced symbol equation for the reaction.

1 Write a word equation. Put the correct chemical symbol or formula under each reactant and product. You cannot guess these – look them up, or ask your teacher.
zinc + copper oxide → zinc oxide + copper
$Zn + CuO \rightarrow ZnO + Cu$

2 Balance the equation. There must be the same number of atoms of each element on each side of the equation. The equation above shows one atom of zinc on each side of the arrow, one atom of copper on each side of the equation, and one atom of copper on each side of the equation. The equation is balanced.

Burning magnesium

Burning magnesium

Magnesium burns in oxygen. The product is magnesium oxide. Follow the steps below to write a balanced symbol equation.

- Write a word equation. Write a formula under each substance.
magnesium + oxygen → magnesium oxide
$Mg + O_2 \rightarrow MgO$
- Balance the amounts of oxygen. There are two atoms of oxygen on the left, and one on the right. Write a big number 2 to the left of the formula of magnesium oxide. Do not change or add any little numbers.
$Mg + O_2 \rightarrow 2MgO$
- The big 2 applies to every atom in the formula that follows it. Here it means that there are two atoms of magnesium and two atoms of oxygen. There are now two oxygen atoms on each side of the equation. The amounts of oxygen are balanced.
- Balance the amounts of magnesium. Add a big 2 to the left of the chemical symbol for magnesium. There are now two atoms of magnesium on each side. The equation is balanced.
$2Mg + O_2 \rightarrow 2MgO$

Burning lithium

Lithium reacts with oxygen to make lithium oxide. The formula of the product is Li_2O.

Write a balanced symbol like this:

- Write a word equation, and a formula under each substance.
  lithium + oxygen → lithium oxide
  $Li + O_2 \rightarrow Li_2O$
- Balance the amounts of oxygen.
  $Li + O_2 \rightarrow 2Li_2O$
  There are two oxygen atoms on each side of the arrow.
- Balance the amounts of lithium.
  $4Li + O_2 \rightarrow 2Li_2O$
  There are four lithium atoms on each side of the arrow.

State symbols

You can add **state symbols** to an equation. State symbols show the states of the substances in a reaction. They are given below. Do not use capital letters.

- (s) for solid
- (l) for liquid
- (g) for gas
- (aq) to show that a substance is dissolved in water.

Zinc reacts with dilute hydrochloric acid to make zinc chloride solution and hydrogen gas. The balanced equation below shows the state of each reactant and product.

$Zn\ (s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2\ (g)$

Q

1. Write a balanced symbol equation for the reaction of sodium and oxygen to form sodium oxide, Na_2O.
2. Write a balanced symbol equation for the displacement reaction of zinc with copper sulfate solution. Include state symbols. The formula for copper sulfate is $CuSO_4$.
3. Write a balanced symbol equation for the reaction of potassium with water to make potassium hydroxide (KOH) and hydrogen (H_2).

!

- Balanced symbol equations show formulae, how atoms are rearranged, and the relative amounts of reactants and products.

Review 10.9

1 Some metals react with oxygen. Write word equations for the reactions of the metals below with oxygen.

a magnesium [1]

b zinc [1]

c potassium [1]

2 The list below shows part of the reactivity series of metals.

sodium
magnesium
zinc
iron
lead
silver
platinum

a Name the most reactive metal in the list above. [1]

b Name one metal that is more reactive than lead. [1]

c Predict what you would observe if you added platinum to dilute hydrochloric acid. [1]

d Predict what you would observe if you left a piece of platinum in a beaker of water for a week. Give a reason for your prediction. [2]

e From the list, suggest a metal that could be attached to a steel ship so that the metal would corrode instead of the steel (mainly iron). [1]

3 A teacher demonstrates the reactions of water with three metals. A student writes her observations in the table below.

Metal	Observations
lithium	Moves around on surface of water. Bubbles produced quickly. Alkaline solution formed.
magnesium	Tiny bubbles form slowly on surface of metal.
potassium	Moves around on surface of water. Bubbles produced quickly, and burn. Alkaline solution formed.

a Name the gas formed in each reaction. [1]

b Describe how the teacher could show that the solution formed in a reaction is alkaline. Describe the changes the student would expect to see. [2]

c Name the alkaline solution formed when lithium reacts with water. [1]

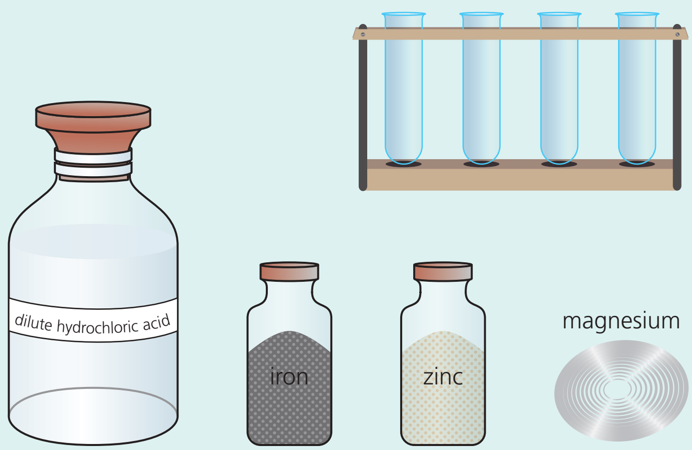
d Write a word equation for the reaction of potassium with water. [2]

e List the metals in the table in order of reactivity, most reactive first. [1]

f Name another metal that reacts with water in a similar way to potassium. [1]

g Suggest why the teacher did not add the metals in the table to dilute acid. [1]

4 Nadish wants to investigate the reactions of metals with dilute hydrochloric acid. He has the apparatus shown in the pictures below.



a Nadish thinks about the variables in his investigation.

i Identify the variable Nadish will change. [1]

ii Identify two variables Nadish must control. [2]

iii Explain why Nadish must control these variables. [1]

b Write an outline plan for the investigation. [2]

c Draw a results table for the investigation. [2]

d Nadish decides to repeat the investigation with a different dilute acid. Suggest why. [1]

e Nadish wants to show that hydrogen gas is produced when metals react with acids. Describe how to do a test to show that hydrogen gas is made. Write down the results you expect. [2]

5 This question is about displacement reactions. The list below shows part of the reactivity series. Use it to help you answer the question.

zinc
iron
lead
copper

a Predict which of the pairs of substances below will react. [2]

i Copper and zinc oxide.

ii Lead and copper oxide.

iii Zinc and lead oxide.

iv Lead and iron oxide.

b Write word equations for the pairs of substances in part (a) that react. [2]

6 Caz puts a piece of zinc in some copper sulfate solution.
A reaction takes place.
The word equation for the reaction is:
zinc + copper sulfate
→ copper + zinc sulfate

a Name the products of the reaction. [1]

b Explain why the reaction is a displacement reaction. [1]

c Caz places a piece of zinc in some nickel nitrate solution.
A displacement reaction takes place.

i Which metal is more reactive, nickel or zinc? Explain how you know. [2]

ii Write a word equation for the reaction. [2]

iii Predict what would happen if Caz placed a piece of nickel in zinc chloride solution. Give a reason for your prediction. [2]

7 Mary wants to find the position of tin in the reactivity series. She has the materials listed below.

Solutions	**Metals**
iron chloride solution	iron
lead nitrate solution	lead
tin chloride solution	tin
zinc chloride solution	zinc

a Mary adds a small piece of zinc to each solution in turn. She writes her observations in the table below.

Solution	Observations on adding zinc metal
iron chloride	silvery metal formed
lead nitrate	grey metal formed
tin chloride	grey metal formed

i What conclusion can Mary make from the observations in the table? [1]

ii Suggest why Mary did not add a piece of zinc to zinc chloride solution. [1]

b Mary adds a small piece of tin to each solution in turn. She writes her observations in the table below.

Solution	Observations on adding tin metal
iron chloride	no reaction
lead nitrate	grey metal formed
zinc chloride	no reaction

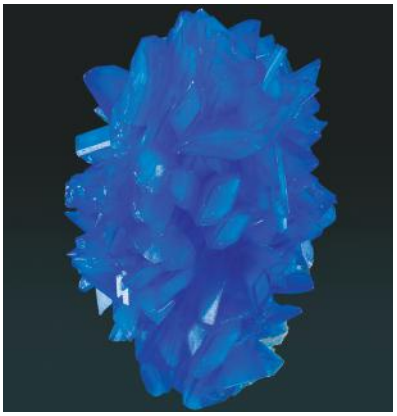
Write a conclusion that Mary can make from the observations in this table. [1]

c Suggest one more investigation that Mary could do to confirm the position of tin in the reactivity series. [2]

11.1 Making salts – acids and metals

Objective

- Describe how to make salts by reacting acids with metals



Copper sulfate crystals.

What are salts?

These pictures show some crystals. What do they have in common?

Manganese chloride crystals.

Nickel nitrate crystals.

The crystals are all samples of **salts**. A salt is a compound made when a metal replaces the hydrogen in an acid.

Different acids make different salts:

- hydrochloric acid makes chlorides
- sulfuric acid makes sulfates
- nitric acid makes nitrates.

Making magnesium chloride

Choosing reactants

Seeta wants to make magnesium chloride. She needs two reactants. One is hydrochloric acid. The other reactant must include magnesium. Seeta could use magnesium metal, magnesium oxide, or magnesium carbonate. She decides to use magnesium metal.

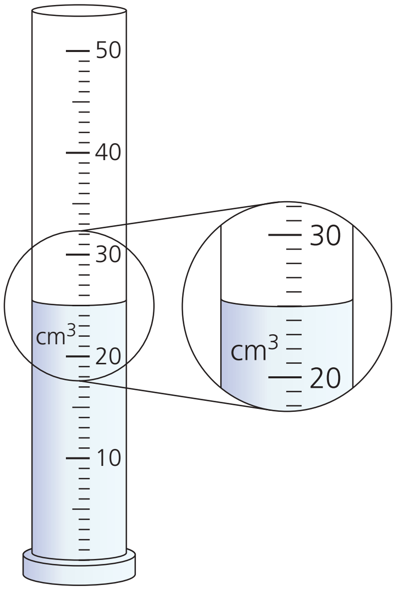
There is a pattern in the reactions of metals with acids. When a metal reacts with an acid, there are two products – a salt and hydrogen.

So when magnesium reacts with hydrochloric acid, the products are magnesium chloride and hydrogen. The word equation for the reaction is:

magnesium + hydrochloric acid → magnesium chloride + hydrogen

The chemical reaction

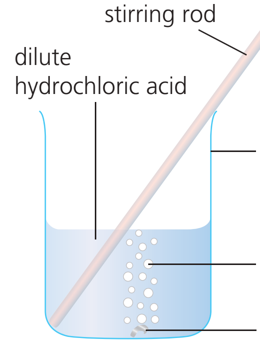
Seeta measures out 25 cm^3 of dilute hydrochloric acid. She uses a measuring cylinder. A measuring cylinder measures smaller differences in volume than a beaker. Seeta pours the acid into a beaker.



There is 25 cm^3 of hydrochloric acid in the measuring cylinder.

Seeta adds a small piece of magnesium ribbon to the acid in the beaker. The magnesium reacts with the acid. Bubbles of hydrogen gas form. After a few seconds, the bubbles stop. All the magnesium has reacted with the acid.

Seeta adds another piece of magnesium to the acid. She continues to add magnesium until there are no more bubbles. A piece of magnesium remains. It has not reacted, because all the acid has been used up.



Magnesium reacts with hydrochloric acid. Bubbles of hydrogen gas form.

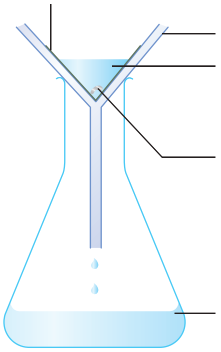
Separating magnesium chloride from the mixture

Seeta's beaker contains a mixture. The mixture includes:

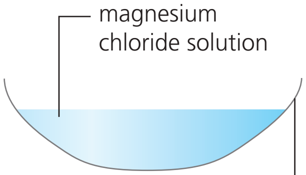
- magnesium chloride solution
- solid magnesium.

Seeta wants to make pure magnesium chloride. First, she filters the mixture. This removes the solid magnesium.

Next, Seeta pours the magnesium chloride solution into an evaporating dish. She heats the solution. Water evaporates. When about half the water has evaporated, Seeta stops heating. She places the evaporating dish in a warm place.



Filtration removes unreacted magnesium from the mixture.



Evaporation removes water from the solution.

A few days later, Seeta looks into the evaporating dish. She sees beautiful white crystals. She has made her salt, magnesium chloride.

Q

1 Jay makes a salt from a metal and an acid. Name the process used to separate the salt solution from unreacted metal.

2 Write a word equation for the reaction of zinc with hydrochloric acid. Name the salt made in this reaction.

3 Name the metal and acid that you could react to make magnesium nitrate crystals.

!

Make salts from acids and metals by:

- reacting an acid with excess metal
- filtering to remove unreacted metal
- heating to remove water.

11.2 Making salts – acids and carbonates

Objective

- Describe how to make salts by reacting acids with carbonates

Killing fungi

Fungi can seriously damage crops. They reduce crop yield and crop quality.

Fungicides destroy fungi. Some farmers use fungicides from natural sources, such as the neem tree. Some farmers use fungicides that are made in factories, such as copper sulfate.

Different fungi attack different plants causing damage to their leaves, seeds or fruit, and roots.

The fungus on these grapes can be controlled using copper sulfate.

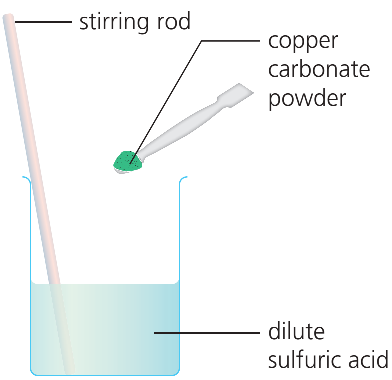
Making copper sulfate

Choosing reactants

Copper sulfate is a salt. It is made in the reactions below.

- **Reaction 1**
  sulfuric acid + copper → copper sulfate + hydrogen
  The acid must be concentrated and the temperature high.
- **Reaction 2**
  sulfuric acid + copper oxide → copper sulfate + water
  Dilute acid may be used.
- **Reaction 3**
  sulfuric acid + copper carbonate → copper sulfate + water + carbon dioxide
  Dilute acid may be used.

On a large scale, copper sulfate is made in reactions 1 and 2. At school, you can use reactions 2 or 3 to make copper sulfate solution. Reaction 1 is too hazardous.



Copper carbonate and sulfuric acid react together to make copper sulfate solution, water, and bubbles of carbon dioxide gas.

The chemical reaction

Sisira plans to make copper sulfate solution from sulfuric acid and copper carbonate.

He measures out 25 cm^3 of acid. He pours it into a beaker. He adds one spatula measure of copper carbonate powder. Carbon dioxide gas forms, and the reacting mixture bubbles. Sisira continues to add copper carbonate. Eventually, no more bubbles form. The reaction has finished.

Separating copper sulfate from the mixture

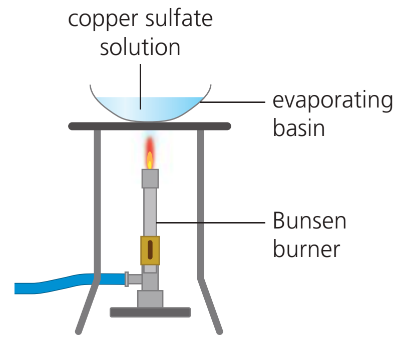
The beaker now contains a mixture of:

- copper sulfate solution
- solid copper carbonate that has not reacted.

Sisira filters the mixture to remove solid copper carbonate from the mixture. He collects the copper sulfate solution in an evaporating dish.

Sisira heats the copper sulfate solution over a flame. Some of its water evaporates. Some of the mixture spits out.

Sisira removes the evaporating dish from the heat, and places it in a warm room for a few days. The remaining water evaporates. Blue copper sulfate crystals are formed.

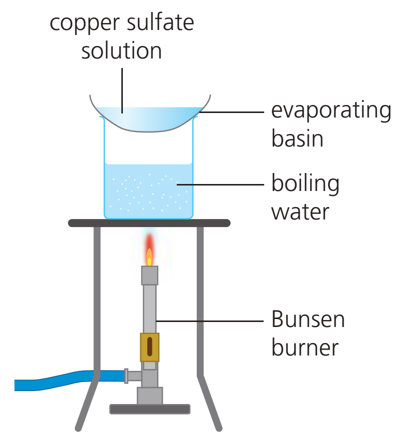


On heating, water evaporates from the copper sulfate solution.

Evaluating and improving methods

Sisira makes a smaller mass of copper sulfate crystals than expected. He lost some of the product when heating the copper sulfate solution.

Sisira decides to improve his method. He repeats the whole experiment. This time, he does not heat the copper sulfate solution over a flame. Instead, he uses a water bath. This heats the solution more evenly. The solution does not spit. Sisira ends up with a greater mass of crystals.



Heating over a water bath.

A pattern of reactions

When a metal reacts with a carbonate, three products are formed:

- a salt
- carbon dioxide
- water.

The equations show some examples:

hydrochloric acid + copper carbonate → copper chloride + carbon dioxide + water

nitric acid + magnesium carbonate → magnesium nitrate + carbon dioxide + water

sulfuric acid + zinc carbonate → zinc sulfate + carbon dioxide + water

Q

1 Maddie makes a salt from a metal carbonate and an acid. Name the process used to separate the salt solution from water.

2 Write a word equation for the reaction of zinc carbonate with hydrochloric acid, and name the salt made in this reaction.

3 Name the metal carbonate and acid that you could react to make zinc nitrate crystals.

!

Make salts from acids and carbonates by:

- reacting an acid with excess metal carbonate
- filtering to remove unreacted metal carbonate
- heating to remove water.

Extension

11.3 Making salts – acids and alkalis

Objective

- Describe how to make salts by reacting acids with alkalis

In 2010, India produced more than 15 million tonnes of sodium chloride. Egypt produced 2.4 million tonnes.

Sodium chloride

Sodium chloride preserves and flavours food. It helps to dye clothes. It is used to make other important chemicals, such as chlorine and sodium hydroxide.

On a large scale, sodium chloride is extracted from the sea, or mined as rock salt. But you can make sodium chloride in the laboratory – read on to find out how.

Making salt

Choosing reactants

How to make sodium chloride from its elements is described on page 114. But burning sodium in chlorine is hazardous and the sodium chloride produced is not pure.

sodium + chlorine → sodium chloride

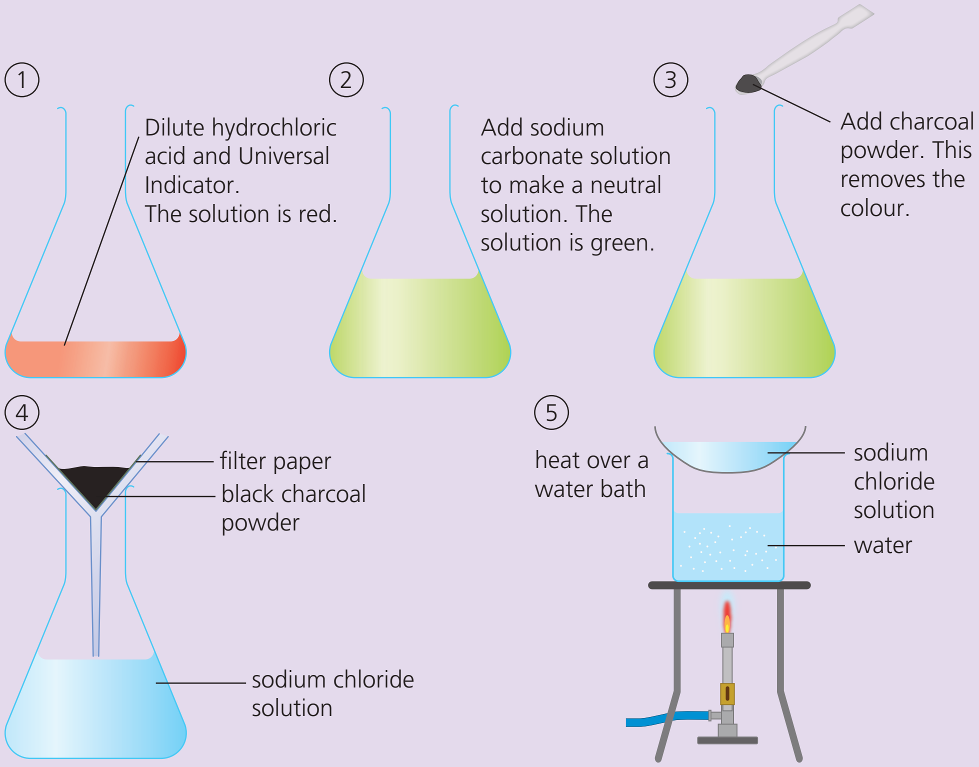
You can also make sodium chloride by neutralising an acid with an alkali.

hydrochloric acid + sodium carbonate → sodium chloride + water

How much sodium carbonate?

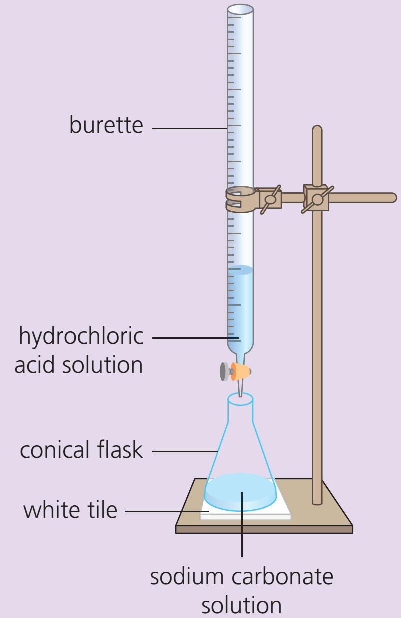
When dilute hydrochloric acid reacts to neutralise sodium carbonate, there is nothing to see. Both reactants are soluble in water. How do you know how much acid to add?

Azalee follows the stages shown in the pictures below to make sodium chloride crystals.



Azalee's method for making sodium chloride crystals.

Bem uses a different method to make sodium chloride solution. He uses a burette and pipette, and indicator solution, to measure the volume of acid needed to exactly neutralise 25.00 cm^3 of sodium carbonate solution. He pours away this mixture, and repeats the method without indicator. Then he heats the sodium chloride solution over a water bath.



Some of Bem's apparatus for making sodium chloride crystals.

Evaluating the two methods

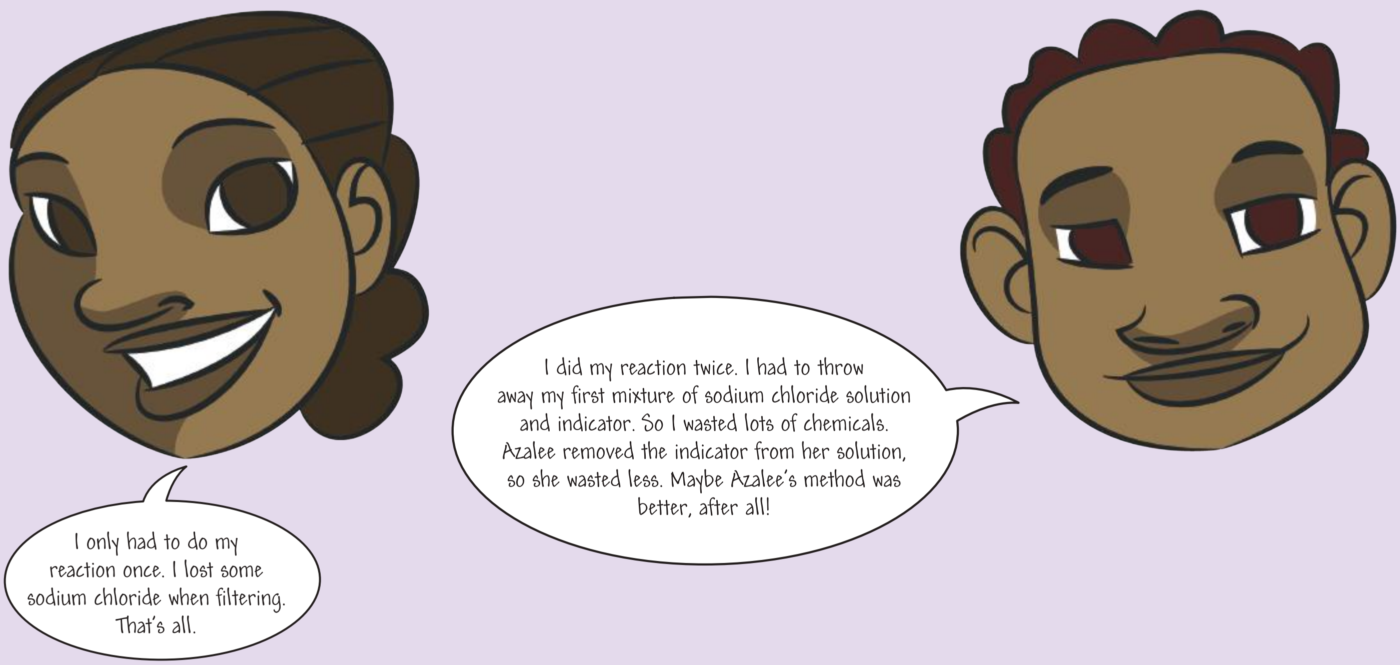
Both Azalee and Bem started with the same amounts of reactants. Bem made more sodium chloride than Azalee. The students evaluated their methods to work out why.

Azalee filtered her mixture to remove the charcoal powder. Some of the sodium chloride solution soaked into the filter paper. Azalee lost some of her product.

Bem did not need to filter his mixture. He did not lose any product in the first stages of his method.

Bem and Azalee heated their sodium chloride solutions over a water bath. Some of the water evaporated. They both lost very little sodium chloride at this stage. This stage does not explain why they made different amounts of sodium chloride. The difference is explained only by Azalee's filtering.

Azalee and Bem discussed their results further.



Q

1. Julia makes a salt by reacting an acid and an alkali. She uses an indicator to find out the volumes of solutions that react together. Describe how to separate the indicator from the salt solution.
2. Write a word equation for the reaction of potassium hydroxide with nitric acid, and name the salt made.
3. Name the acid and alkali that you could react to make potassium chloride crystals.

!

Make salts from acids and alkalis by:

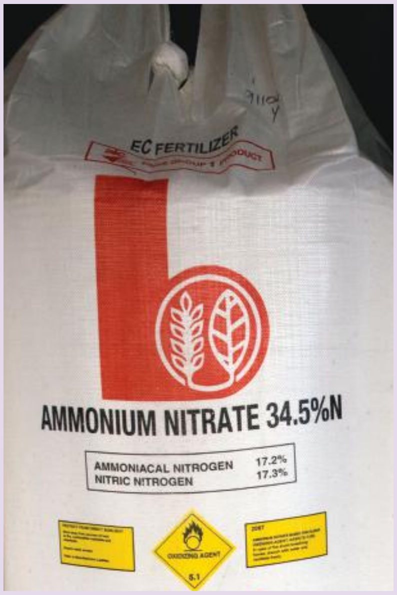
- reacting an acid with an alkali – use an indicator
- heating to remove water.

Extension 11.4

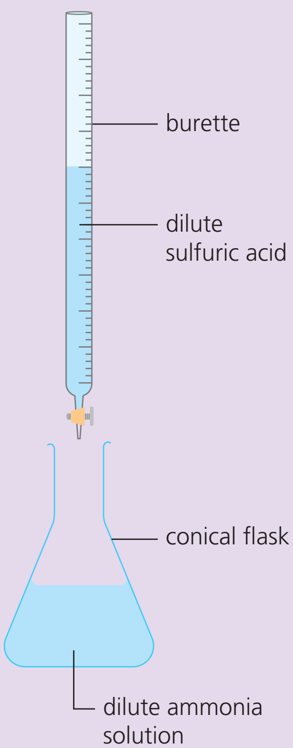
Making salts – fertilisers

Objective

- Identify salts used as fertilisers



The bag shows the elements in a fertiliser.



Madu's apparatus.

Why add fertiliser?

Plants use water, and carbon dioxide from the air, to make glucose. Glucose is a compound made up of the elements carbon, hydrogen, and oxygen. Its formula is $C_6H_{12}O_6$.

Plants need other elements, too. They need nitrogen to make proteins. They need phosphorus to form flowers and seeds. They need potassium to protect them against disease.

Plants get nitrogen, phosphorus, and potassium minerals from the soil. Farmers increase crop yields by adding fertiliser to the soil. Some fertilisers, such as manure and compost, occur naturally. Other fertilisers are made in factories.

Making fertilisers

Most nitrogen fertilisers are made from ammonia. Ammonia is a compound of nitrogen and hydrogen. Its formula is NH_3.

Ammonia dissolves in water to make an alkaline solution. In the laboratory, you can react ammonia solution with acids. These neutralisation reactions make salts. The salts are used as fertilisers.

Which salts?

The equations show the reactions of ammonia solution with acids.

ammonia + sulfuric acid → ammonium sulfate + water

ammonia + hydrochloric acid → ammonium chloride + water

ammonia + nitric acid → ammonium nitrate + water

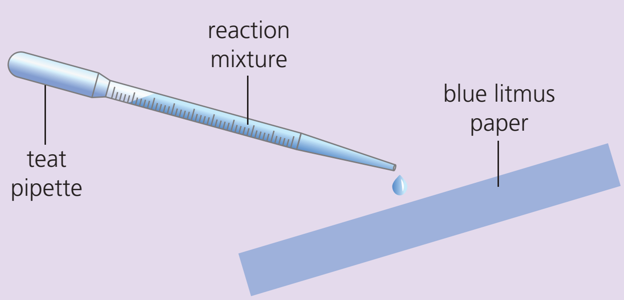
Ammonium nitrate contains more nitrogen than the other ammonium salts. Farmers add ammonium sulfate to alkaline soil. The salt provides nitrogen for plant growth, and makes the soil less acidic.

Making ammonium sulfate

Madu plans to make ammonium sulfate. He pours 25 cm^3 of ammonia solution into a conical flask. He pours sulfuric acid into a burette.

Madu adds 1 cm^3 of acid to the ammonia solution in the flask. The acid reacts with some of the ammonia solution. Madu removes a drop of the mixture. He drops it onto blue litmus paper. The paper remains blue. The flask contains some ammonia solution that has not reacted.

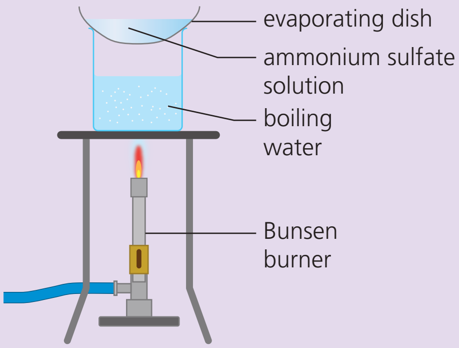
Madu repeats the step above several times. He adds more and more acid. Eventually, the litmus goes red. Madu has now added enough acid to neutralise all the ammonia. The flask now contains a mixture of ammonium sulfate and water. There is a tiny bit of extra acid, too.



Madu removes a drop of mixture from the flask. He drops it onto blue litmus paper.

Separating ammonium sulfate from the mixture

Madu uses evaporation to remove water from the ammonium sulfate solution.

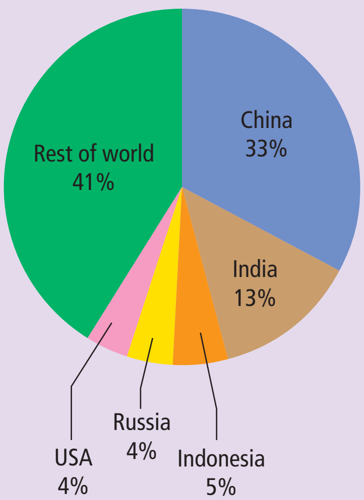


Evaporation removes water from ammonium sulfate solution.

When about half the water has evaporated, Madu stops heating. He leaves the ammonium sulfate solution in a warm place. The rest of the water evaporates. Ammonium sulfate crystals remain.

Fertiliser production

We use huge amounts of fertiliser. One common fertiliser that is made from ammonia is urea. In 2009, factories made about 190 000 million tonnes of urea. The pie chart shows the five countries that produced the most urea.



The top five urea-producing countries in 2009.

Q

1 Name the fertiliser made by reacting ammonia solution with dilute nitric acid.

2 Name the process that removes water from a solution of a fertiliser.

!

- Ammonium nitrate and ammonium sulfate are useful fertilisers.

Review 11.5

1 From the list below, choose the one best definition of a salt.

A compound made when an element replaces the hydrogen in an acid.

A compound made when a metal replaces the hydrogen in an acid.

A substance that preserves and flavours food.

Chloride and sulfate compounds. [1]

2 Name the salts made when the following pairs of substances react.

- **a** Magnesium and sulfuric acid. [1]
- **b** Zinc and hydrochloric acid. [1]
- **c** Magnesium and nitric acid. [1]
- **d** Copper carbonate and hydrochloric acid. [1]
- **e** Zinc oxide and sulfuric acid. [1]
- **f** Copper oxide and nitric acid. [1]

3 Hydrogen gas is produced when a metal reacts with an acid.

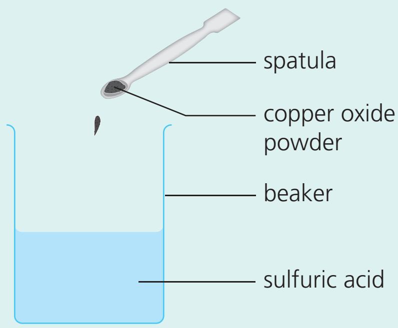
- **a** Describe how to test for hydrogen gas. [1]
- **b** Describe what you would observe in your test if hydrogen is present. [1]

4 Copy and complete the word equations below.

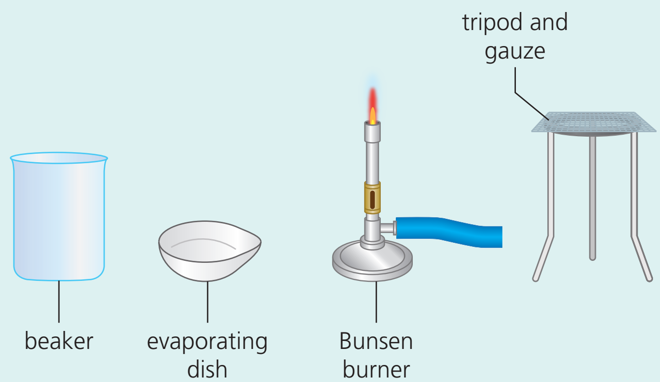
- **a** magnesium + nitric acid → [1]
- **b** zinc + sulfuric acid → [1]
- **c** magnesium + hydrochloric acid → [1]
- **d** copper carbonate + hydrochloric acid → [1]
- **e** zinc oxide + nitric acid → [1]

5 Zafira wants to make some copper sulfate crystals.

- **a** Name the acid she needs. [1]
- **b** Zafira has a choice. She could add either copper carbonate or copper oxide to the acid to make her crystals.
  - **i** Name the products of the reaction of copper carbonate with sulfuric acid. [1]
  - **ii** Write a word equation for the reaction of copper carbonate with sulfuric acid. [1]
  - **iii** Name the products of the reaction of copper oxide with sulfuric acid. [1]
  - **iv** Write a word equation for the reaction of copper oxide with sulfuric acid. [1]
- **c** Zafira decides to use copper oxide. She places 25 cm^3 of sulfuric acid in a beaker. She adds black copper oxide powder until the copper oxide stops reacting.

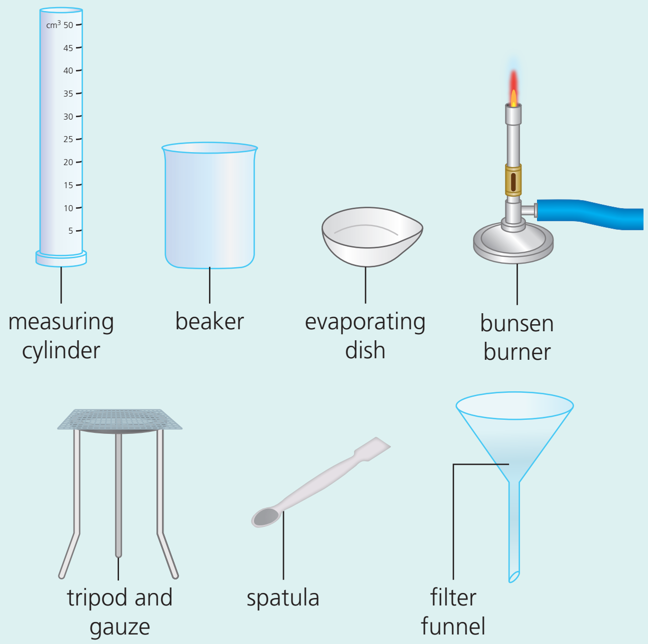


  - **i** Name the three substances in the beaker when Zafira has finished adding copper oxide powder. [3]
  - **ii** Describe how Zafira can separate the copper oxide powder from the other substances in the mixture. [1]
- **d** Zafira now has a solution of copper sulfate. Describe how she can use the apparatus below to obtain copper sulfate crystals from the solution.



[3]

6 Rizki uses the apparatus below to make copper chloride crystals.



a Rizki makes copper chloride from copper carbonate and hydrochloric acid.

i Name the gas made in the reaction. [1]

ii Write a word equation for the reaction. [2]

b Rizki follows the steps below for making his crystals, but they are not in the correct order.

A	Measure out 25 cm^3 of hydrochloric acid.
B	Pour the solution into an evaporating dish.
C	Heat the solution until about half its water has evaporated.
D	Add copper carbonate, spatula by spatula, until there is no more bubbling.
E	Place the evaporating dish on a water bath.
F	Filter the mixture. Keep the solution.
G	Place the evaporating dish and its contents in a warm room.
H	Wait for a few days to allow the rest of the water to evaporate.

Write the correct order for the steps above. The first one is A. [5]

7 Lia plans to make zinc chloride crystals. She decides to react zinc metal with hydrochloric acid.

a The products of the reaction are zinc chloride solution and hydrogen gas. Write a word equation for the reaction. [2]

b Lia uses a secondary source to list the hazards of the reactants and products.

Substance	Hazard
zinc metal	Low hazard
dilute hydrochloric acid	Low hazard. May cause harm in eyes or in a cut.
hydrogen gas	Extremely flammable. Forms explosive mixture with air.
zinc chloride solution (dilute)	Low hazard.
zinc chloride crystals and concentrated solutions of zinc chloride	Corrosive. Burns skin. Harmful if swallowed.

Lia takes the precautions below to reduce risks from the hazards. Give one reason for each precaution.

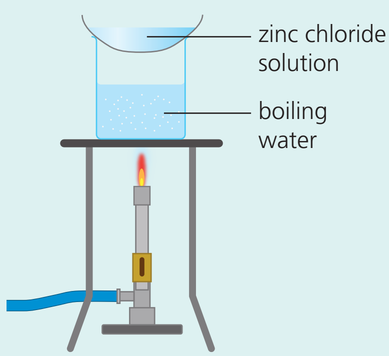
i Be careful not to spill the acid. [1]

ii When adding zinc metal to the acid, make sure there are no flames nearby. [1]

iii Wear eye protection at all stages of the experiment. [1]

iv Do not touch the zinc chloride crystals. [1]

c Lia makes zinc chloride solution. She pours the solution into an evaporating dish. She does not heat the solution directly. Instead, she heats the solution over a water bath. Suggest why.



[1]

12.1 Rates of reaction

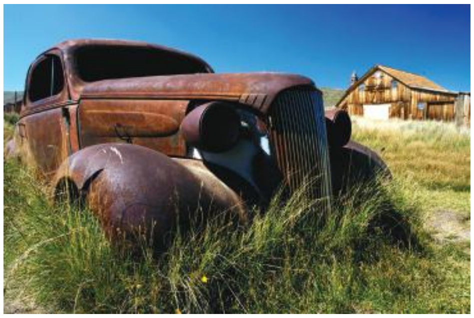
Objective

- Understand how to follow the rate of a reaction that produces a gas

Fast or slow?

Fireworks explode in the sky. A car rusts. Some chemical reactions, such as those in fireworks, happen very quickly. Others, such as rusting, are much slower.

Chemical reactions in fireworks are very fast.



Rusting reactions are very slow.

Chemists need to control reaction rates. They may try to slow down rusting reactions. They may try to speed up reactions that make useful chemicals, such as soap, fertilisers, or medicines.

Following a reaction

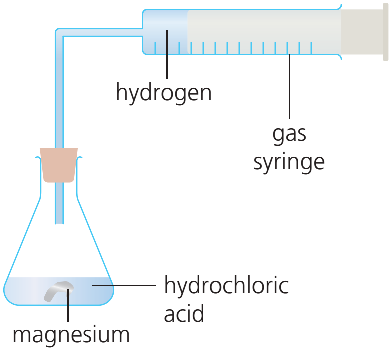
Before chemists can control reaction rates, they need to find out how fast a reaction is. You cannot tell how quickly a reaction happens just by looking at its equation. You need to do an experiment to find out – how quickly is a reactant used up? How quickly does a product form?

Vijay wants to find out about the rate of the reaction of magnesium with hydrochloric acid. The equation for the reaction is below.

magnesium + hydrochloric acid → magnesium chloride + hydrogen

Obtaining and presenting evidence

Vijay sets up the apparatus on the right. He drops a piece of magnesium into the acid. He observes bubbles. The bubbles contain hydrogen gas. As the hydrogen gas forms, it goes into the gas syringe. The plunger moves out.



Vijay measures the total volume of gas that has been produced by the reaction at the end of each minute.
He draws a table for his results:

- The variable he changes (time) is in the left column.
- The variable he measures (volume of gas) is in the big right column.

Vijay wants to reduce error and make sure his results are reliable, so he decides to repeat his investigation. His table has space for three results for each test, and for an average value.

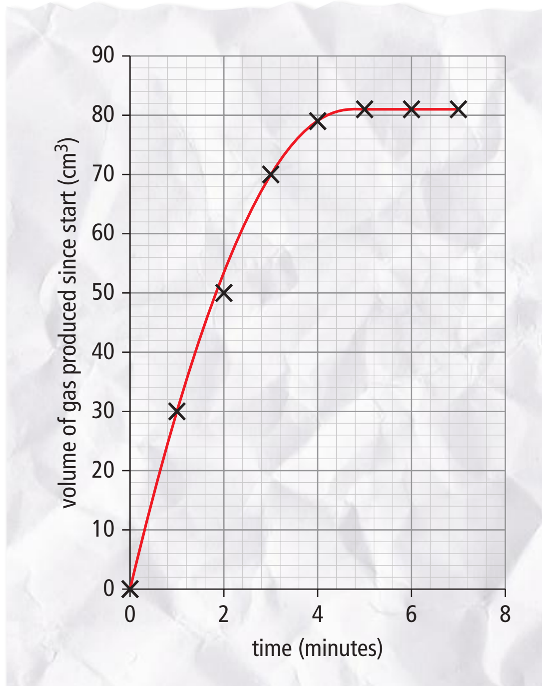
Time (minutes)	Total volume of gas formed by the end of this minute (cm^3)			
	1	2	3	average
0	0	0	0	0
1	31	30	32	31
2	45	47	49	47
3	64	68	66	66
4	69	69	66	68
5	76	76	79	77
6	83	85	81	83
7	83	83	83	83
8	84	82	83	83

Vijay chooses how to present his results. The variable he changes, and the variable he measures, are continuous. This means he can plot a line graph:

- The scale for the variable he changes is on the *x*-axis.
- The scale for the variable he measures is on the *y*-axis.

Vijay makes sure the numbers on each axis are evenly spaced.

Vijay draws a cross for each point. He then draws a line of best fit. This is a smooth curve. The number of points above and below the line are similar.



Describing patterns and interpreting results

At first, the graph rises steeply. This shows that hydrogen is formed quickly at the start of the reaction. The rate of the reaction is fast. Then the slope of the graph gets less steep. This shows that the reaction is slowing down. The rate of the reaction is slower.

From the sixth minute onwards, the graph does not go up any more. No more hydrogen gas is being made. This shows that the reaction has finished. All the magnesium has been used up, so there is nothing left for the acid to react with.

Q

1. Give an example of a very fast reaction, and a very slow reaction.
2. Use the graph above to estimate the volume of gas made during the first 2.5 minutes of the reaction.
3. Explain how the graph shows when the reaction has finished.

!

- In a reaction that makes a gas, the total amount of gas made by the end of each minute shows how the rate of reaction changes over time.

12.2 Concentration and reaction rate

Objective

- Describe and explain how concentration affects reaction rate

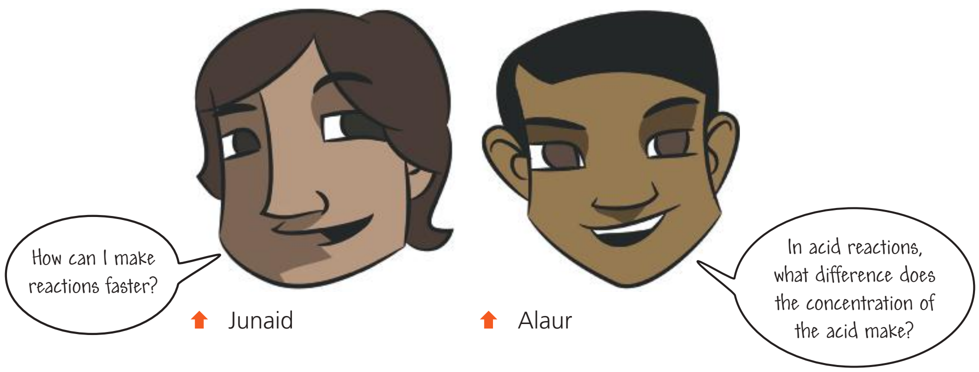
Companies employ chemists to tell them how to speed up reactions.

Why speed up reactions?

Tara is a chemist. She works for a company that makes medicines. The company wants to make its medicines as quickly as possible, and as cheaply as possible. Tara investigates the conditions that speed up reactions that make medicines.

Questioning reaction rates

Some students ask questions about reaction rates.



The students decide to investigate Alaur's question. It is focused. They can get an answer to the question in just one hour.

Planning an investigation

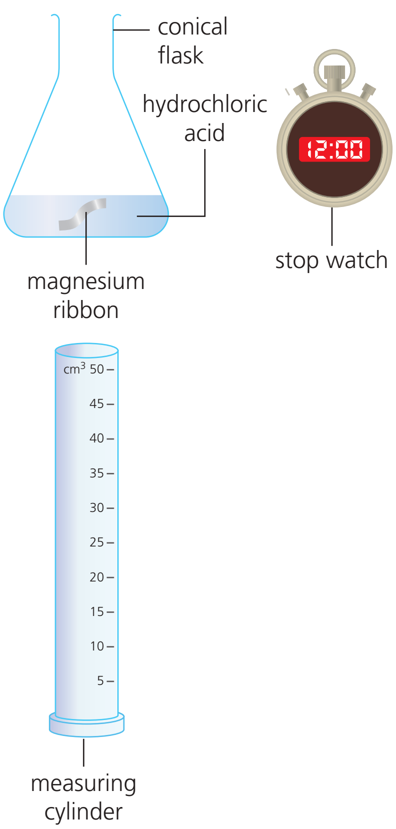
The students decide to investigate the reaction of magnesium with hydrochloric acid. Their teacher gives them the apparatus below.

The students list the variables in the investigation:

- time for magnesium ribbon to finish reacting
- amount of magnesium ribbon
- concentration of acid
- temperature
- volume of acid

The students decide to change the concentration of acid. They will measure the time for the magnesium ribbon to finish reacting. They will keep the other two variables constant, so that their test is fair.

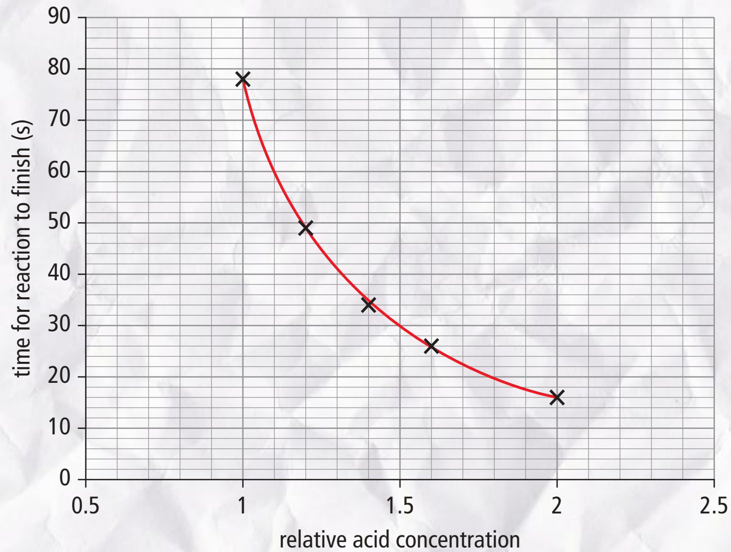
The students wonder how much magnesium ribbon to use. They do some preliminary work to find out. This involves adding different lengths of magnesium ribbon to acids of different concentration. They find the length of ribbon that reacts with the most and least concentrated acids in a sensible time.



Apparatus for investigating the effect of acid concentration on rate of reaction.

Presenting evidence

The students write their results in a table. Next, they plot the points on a graph, and draw a line of best fit.



The graph shows how reaction time varies with acid concentration.

Considering evidence

The students write a conclusion for their investigation.

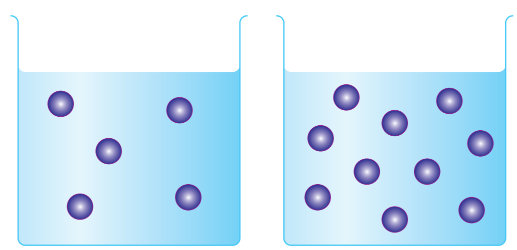
> The graph shows a correlation between acid concentration and reaction time. As acid concentration increases, reaction time decreases. This means that when the acid concentration is higher, the rate of reaction is faster.

The students need to improve their conclusion. They must give a scientific explanation for the correlation.

Explaining the correlation between concentration and rate

The concentration of a solution tells you how much solute is dissolved in the solvent. The more concentrated an acid solution, the greater the number of acid particles dissolved in a certain volume of solution.

Substances only react when their particles hit each other, or collide. The more concentrated an acid, the more frequently its particles collide with magnesium particles … and the faster the reaction.



If the beaker on the left represents a less concentrated acid … then the beaker on the right represents a more concentrated acid. Water particles are not shown on the diagrams. *Not to scale.*

Q

1. Explain why the students displayed their results on a line graph, not a bar chart.
2. Describe the correlation between acid concentration and reaction rate.
3. Use ideas about particles to explain the correlation you described in question 2.
4. A student wonders whether the results would be similar if they used a different acid. Suggest how they could investigate.

!

- For reactions involving solutions, the more concentrated the solution, the faster the reaction.

12.3 Temperature and reaction rate

Objective

- Describe and explain how temperature affects reaction rate

Cooking temperatures

Farai and Ibrahim chop potatoes. Ibrahim adds his potatoes to boiling water, at 100°C. They cook in 12 minutes. Farai adds potatoes to boiling oil, at 200°C. They cook more quickly.

The chemical reactions that happen when potatoes cook are quicker at higher temperatures. The reaction rates are faster. Is this true for other reactions?

The higher the temperature, the faster food cooks.

Investigation rates and temperature

Ideas and evidence

Reactions happen when moving particles collide. At higher temperatures, particles move more quickly, and collide more frequently.

Farai uses this scientific explanation to make a prediction.

Prediction:
The higher the temperature, the more frequently particles collide.
I predict that the higher the temperature, the faster the reaction.

Planning an investigation

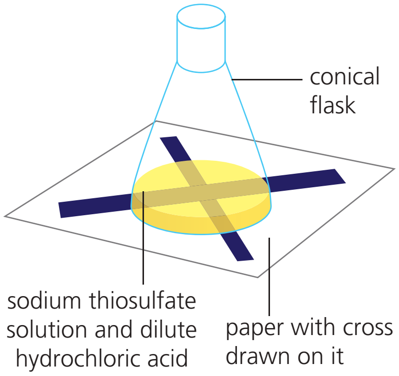
Sodium thiosulfate solution reacts with hydrochloric acid to make four products. The word equation summarises the reaction:

sodium thiosulfate + hydrochloric acid → sodium chloride + water + sulfur dioxide + sulfur

The sulfur is formed as a solid. It is insoluble in water, so it makes the reaction mixture cloudy.

Farai draws a cross on a piece of paper. He stands a conical flask on the cross. He pour sodium thiosulfate solution into the flask. Then he adds hydrochloric acid. He starts the timer.

Gradually, solid sulfur forms. Soon, the mixture is so cloudy that Farai can no longer see the cross. He does the same experiment using acid at four different temperatures. He repeats the whole investigation twice more, to reduce error and make his results more reliable. Will his prediction be correct?



The reaction of sodium thiosulfate solution with hydrochloric acid makes solid sulfur. Soon, Farai will not be able to see the cross under the flask.

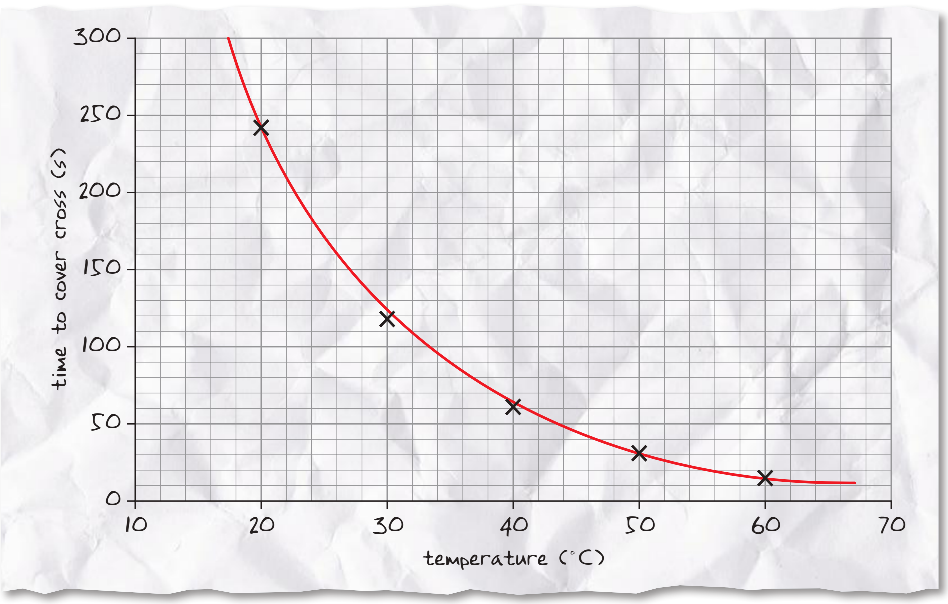
Presenting results

Farai writes his results in a table.

Temperature of acid (°C)	Time to cover cross (seconds)			
	1	2	3	average
20	244	240	242	242
30	119	117	118	118
40	59	61	63	61
50	67	32	30	31
60	13	16	16	15

Farai notices that the first result for 50 °C is very different from the other results at this temperature. The result is anomalous. He decides not to include this result when calculating the average time for 50 °C.

Farai knows that both the variable he changes (temperature) and the variable he measures (time) are continuous. He decides to draw a line graph. Drawing a graph makes it easier to spot patterns in results.



Considering evidence

The graph shows a correlation – the higher the temperature, the faster the reaction. As temperature increases, so does the rate of reaction.

This finding agrees with Farai's prediction. He is now more confident that the explanation on which he based his prediction is correct.

Q

1 Describe the correlation between temperature and rate of reaction.

2 Use ideas about particles to explain the correlation between temperature and rate of reaction.

3 Farai wants to investigate whether increasing temperature increases the rate of the reaction of magnesium with hydrochloric acid. Describe an investigation he could do to find out.

!

- Increasing temperature increases reaction rate.

12.4 Surface area and reaction rate

Objective

- Describe and explain how temperature affects reaction rate

Flour tragedy

In 1965 in London, England, an explosion at a flour mill killed four people and injured 31. Why does flour explode?

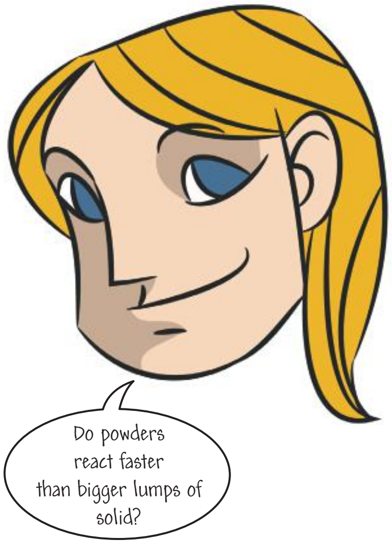
Flour is made up of tiny grains. In the air, the grains spread out, as dust. Particles from the air – including oxygen molecules – surround the flour grains. Then someone lights a match. Instantly, a flour grain catches fire. It lights the other grains near it. A flame flashes through the flour cloud. This is the explosion. Other powders form explosive mixtures with air, too, including fine sugar, coal dust, and sawdust.

Flour and other powders can explode in the laboratory.

Surface area and reaction rate

Making a prediction

Catherine wants to investigate reactions involving powders. She asks a question.



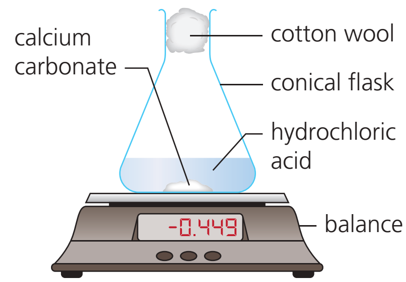
Catherine decides to investigate the reaction of dilute hydrochloric acid with calcium carbonate. The equation below summarises the reaction.

calcium carbonate + hydrochloric acid → calcium chloride + carbon dioxide + water

Catherine knows that substances react when their particles collide. In the reaction above, particles from hydrochloric acid react only with particles on the surface of a piece of calcium carbonate. Ten grams of calcium carbonate powder has a bigger surface area than ten grams of calcium carbonate lumps. This means that the powder has more particles that are available to react.

Catherine uses this knowledge to make a prediction.

Calcium carbonate powder will react with dilute acid more quickly than big lumps of calcium carbonate.



Apparatus to investigate how surface area affects reaction rate.

Obtaining evidence

Catherine sets up the apparatus in the diagram. As carbon dioxide is made, it escapes from the apparatus. The mass of the flask and its contents decreases.

Catherine adds a big lump of calcium carbonate to dilute hydrochloric acid. She measures the time for the mass to decrease by 1.0 g.

Next, Catherine adds calcium carbonate powder to dilute hydrochloric acid. She uses the same mass of calcium carbonate as before. She measures the time for the mass to decrease by 1.0 g.

Finally, Catherine adds small lumps of calcium carbonate powder to dilute hydrochloric acid. Again, she keeps the other variables constant. She measures the time for the mass to decrease by 1.0 g.

Presenting evidence

The table shows Catherine's results.

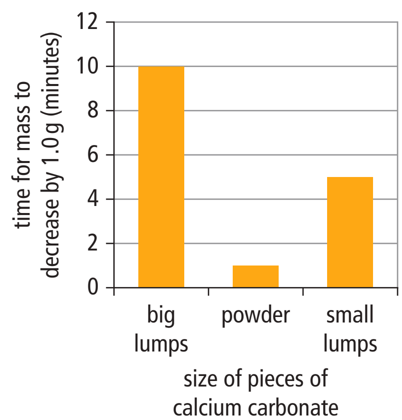
Size of calcium carbonate pieces	Time for total mass to decrease by 1.0 g (mins)
big lump	10
powder	1
small lumps	5

Catherine wants to draw a graph. This will make it easier to spot patterns in her results. The variable she changes (the size of the pieces of calcium carbonate) is discrete. This means she must draw a bar chart.

Considering evidence

The bar chart shows that, as surface area increases, the time for the reaction decreases. Therefore, increasing surface area increases reaction rate.

Catherine's prediction is correct. Increasing the surface area increases the number of particles available for reaction. Acid particles collide with solid particles more frequently, so the reaction rate increases.



The bar chart shows how surface area affects reaction time.

Q

1. Identify the variables Catherine needs to control in her investigation.
2. Describe the correlation between surface area and rate of reaction.
3. Use ideas about particles to explain the correlation between surface area and rate of reaction.

!

- Increasing the surface area of solid reactants increases reaction rate.

12.5 Catalysts and reaction rate

Objective

- Describe and explain how catalysts affect reaction rate

A natural catalyst

Sarah chews a piece of bread. She chews it for a long time. After a while, there is a sweet taste in her mouth.

There has been a chemical reaction in Sarah's mouth. Starch molecules from the bread have broken down to form glucose. Glucose is a sugar. The reaction happens very, very slowly on its own.

In our mouths there is a substance that makes the reaction happen more quickly. This substance is an **enzyme** called salivary amylase. All enzymes are examples of **catalysts**. A catalyst is a substance that speeds up a reaction without being used up in the reaction.

Chewing white bread for a long time makes a substance with a sweet taste.

Another natural catalyst

Hydrogen peroxide is a bleach. It makes paper white. Hydrogen peroxide is normally diluted with water. It breaks down very slowly to make water and oxygen gas. The reaction is called a decomposition reaction.

hydrogen peroxide → water + oxygen

Amber has a test tube of hydrogen peroxide solution. She adds a small piece of chicken liver to the solution. It bubbles vigorously. A substance in the liver catalyses the decomposition reaction. The catalyst is an enzyme called catalase. It speeds up the reaction without being used up.

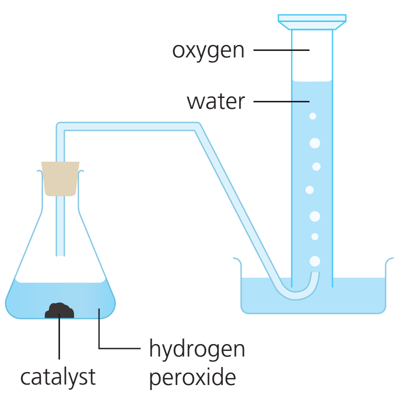
Catalase in liver catalyses the decomposition reaction of hydrogen peroxide.

Testing for oxygen gas

Amber puts a glowing splint into the foam above the reaction mixture. The glowing splint relights. This shows that the gas produced in the reaction is oxygen.

Testing catalysts

Amber wants to test some other substances. Which will be the best catalyst for the decomposition of hydrogen peroxide? She sets up the apparatus below.



Apparatus for measuring the volume of oxygen produced when hydrogen peroxide decomposes.

Amber draws a table for her results.

Name of substance	Volume of oxygen gas produced in 1 minute (cm^3)
manganese(IV) oxide	25.0
lead(IV) oxide	28.0
iron(III) oxide	0
copper(II) oxide	1.0
zinc oxide	0
hydrogen peroxide only	0

She studies her data, and writes a conclusion.

Manganese(IV) oxide and lead(IV) oxide are the best catalysts for the decomposition reaction. I know this because they produced the biggest volumes of oxygen gas in 1 minute.

Iron(III) oxide and zinc oxide do not catalyse the decomposition reaction of hydrogen peroxide.

How do catalysts work?

Catalysts make it easier for a reaction to start. The decomposition reaction of hydrogen peroxide happens on the surface of the catalyst powders.

Using catalysts

Catalysts are vital in the chemical industry. They speed reactions up, meaning that more product is made in a shorter time. For example, iron catalyses the reaction of hydrogen with nitrogen to make ammonia. Ammonia makes fertilisers and explosives.

Catalytic converters in car exhaust systems contain metal catalysts such as platinum, rhodium, and palladium. The metals catalyse reactions such as the one below, in which poisonous carbon monoxide is converted to carbon dioxide, which is not poisonous.

carbon monoxide + oxygen → carbon dioxide

Catalytic converters in cars convert harmful gases to less harmful ones.

Q

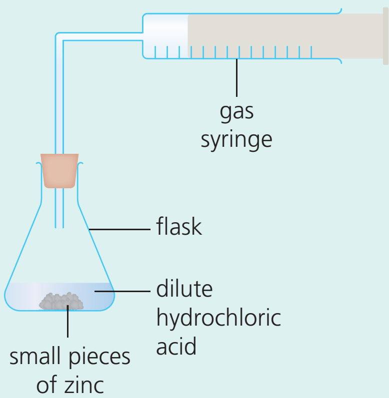
1 Explain what catalysts do.
2 Give examples of three catalysts.
3 Explain how catalysts speed up reactions.

!

- Catalysts speed up reactions without themselves being used up in the reaction.

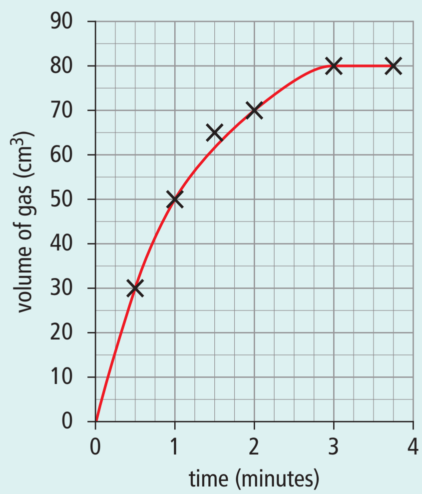
Review 12.6

1 Abbas investigates the reaction of zinc with hydrochloric acid. He pours 25 cm^3 of the acid into a conical flask. He adds small pieces of zinc. He collects the gas in a syringe.



a The products of the reaction are zinc chloride and hydrogen. Write a word equation for the reaction. [1]

b Abbas measures the volume of gas collected every minute. He plots a graph of his results.



i Between which times is the reaction fastest? Choose from the list below. [1]

Between 0 and 1 minute.
Between 2 and 3 minutes.
Between 3 and 4 minutes.

ii After how many minutes does the reaction finish? [1]

iii What is the total volume of gas made in the investigation? [1]

c Abbas wants to find out how the rate of reaction changes if he increases the concentration of acid.

i Name two variables he should keep the same in his investigation. [2]

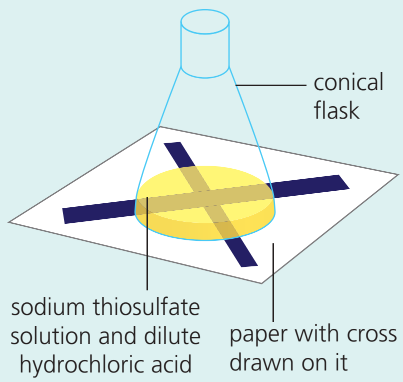
ii Explain why he should keep these variables the same. [1]

iii Draw a table in which Abbas could write his results. [1]

2 Arifa investigates the reaction of sodium thiosulfate solution with hydrochloric acid.

One of the products of the reaction is sulfur. This forms as a solid.

As sulfur is made, it hides the cross under the conical flask. Arifa measures the time taken for the cross to disappear.



a Arifa wants to find out how changing the temperature affects the rate of the reaction.

i Name the variable Arifa changes. [1]

ii Name the variable Arifa measures. [1]

iii Name three variables Arifa should control. [3]

b Arifa's results are in the table.

Temperature (°C)	Time for cross to disappear (s)			
	1	2	3	average
20	400	403	397	400
30	200	202	198	
40	104	100	102	102
50	47	50	47	48
60	24	27	27	26
70	148	13	13	58

i Suggest why Arifa measures the time for the cross to disappear three times at each temperature. [1]

ii Calculate the missing average. [1]

iii Plot Arifa's results on a graph, and draw a line of best fit. [1]

- **iv** Identify the anomalous result in the investigation. [1]
- **v** Describe the correlation shown by the graph. [1]

c Use ideas about particles and collisions to help you explain the correlation shown by the graph. [2]

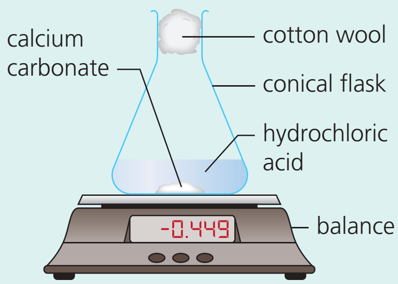
3 Rashid investigates the reaction of hydrochloric acid with calcium carbonate.

The equation for the reaction is

hydrochloric acid + calcium carbonate → calcium chloride + carbon dioxide + water

a Predict which product of the reaction is formed as a gas. [1]

b Rashid sets up the apparatus below.



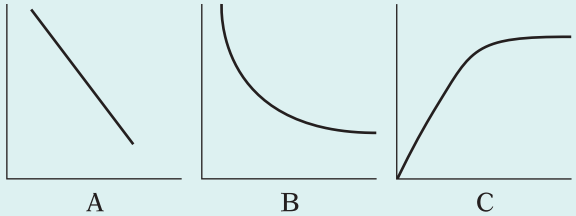
- **i** Rashid predicts that, as the reaction progresses, the mass of the reaction mixture in the flask will decrease.

  Which of the reasons below best explains why the mass decreases?

  The product that is formed as a gas dissolves in the reaction mixture.
  The product that is formed as a gas escapes into the air.
  The product that is formed as a gas is made up of atoms of two elements. [1]

- **ii** Rashid records the mass of the reactant mixture every minute. He plots a graph of his results.

  Predict which of the graphs below best represents Rashid's results.



[1]

c Rashid wants to investigate how the size of the pieces of calcium carbonate affect the reaction rate.

He has three sizes of calcium carbonate pieces – big lumps, small lumps, and powder.

He decides to measure the time taken for 1.0 g of gas to be made with each size of calcium carbonate pieces.

- **i** Name the variable he changes. [1]
- **ii** Name the variable he measures. [1]
- **iii** Name two variables Rashid must keep constant. [1]
- **iv** Draw a table for Rashid's results. [2]
- **v** Rashid finds that the powder reacts most quickly.

  Which of the reasons below best explains why?

  For a certain mass of calcium carbonate, the powder has the smallest surface area.
  For a certain mass of calcium carbonate, the powder has the biggest surface area.
  For a certain mass of calcium carbonate, the powder has the highest concentration.

4 The equation below shows the products when hydrogen peroxide decomposes:

hydrogen peroxide → water + oxygen

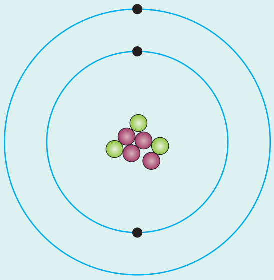
Manganese(IV) oxide catalyses the reaction.

a What is a catalyst? [2]

b Salama wants to investigate the effects of different catalysts on the reaction. She measures the volume of oxygen gas produced in one minute by four different catalysts. Draw a table for Salama's investigation. [2]

Review
Stage 9

1 The diagram shows the sub-atomic particles in an atom of an element.

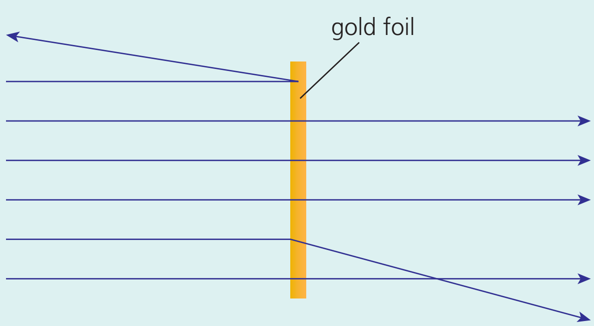


a Give the number of sub-atomic particles in the nucleus of the atom. [1]

b Name the two types of particles found in the nucleus. [2]

c Predict which group of the periodic table the element is in. [1]

2 Three scientists, Geiger, Marsden, and Rutherford, fired small positively-charged particles at thin sheet of gold foil.
The diagram shows the paths of some of the particles.



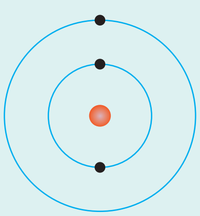
a Explain why some of the particles travelled straight through the foil. [1]

b Give the name of the part of the atom which causes some particles to change direction. [1]

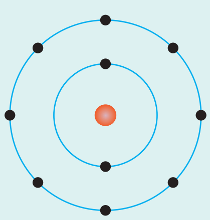
c Explain why more particles travel straight through the foil than change direction. [1]

3 The diagrams below show the electron arrangements of atoms of four elements.

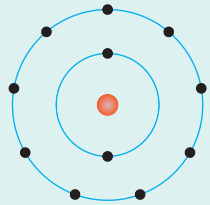
A



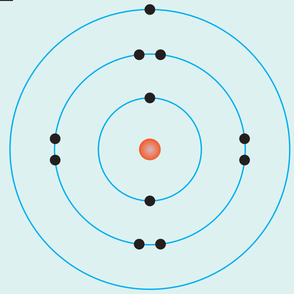
B



C



D



a Which electron arrangement is incorrect? [1]

b Which two elements are in the same group of the periodic table? [1]

c Which element is in period three of the periodic table? [1]

4 The table below shows the densities of some group 2 elements.

Element	Density (g/cm^3)
calcium	1.54
strontium	
barium	3.51
radium	5.00

a Plot the data in the table on a bar chart. [3]

b Use your bar chart to predict the density of strontium. [1]

5 The tables give data for elements in two groups of the periodic table.

Table A.

Element	Boiling point (°C)
lithium	1330
sodium	890
potassium	774

Table B.

Element	Boiling point (°C)
chlorine	–35
bromine	59
iodine	184

a Use the periodic table to give the group numbers of the elements in Table A and Table B. [2]

b Describe the trend in boiling points for the elements in Table A. [1]

c Compare the trend you described in part (b) with the trend in boiling points for the elements in Table B. [2]

6 Iveta neutralises an acid with an alkali. She records the temperatures of the solutions before and after the reaction.

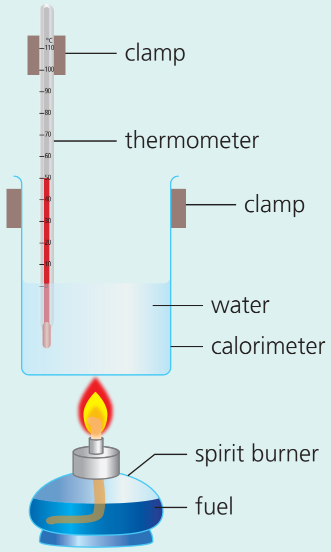
She writes her results in a table.

Temperature of acid before reaction (°C)	21
Temperature of alkali before reaction (°C)	23
Maximum temperature reached after reaction (°C)	69

a Explain how the results show that the neutralisation reaction is exothermic. [1]

b Name one other type of reaction that is usually exothermic. [1]

7 Artem investigates the energy given out by four fuels. He sets up the apparatus below.



He measures the temperature change of the water when he burns 1 g of each fuel.

a Name the variable Artem changes, and the variable he measures. [1]

b Name two variables Artem must control in the investigation. [1]

c Artem obtains the results in the table.

Fuel	Temperature before heating (°C)	Temperature after heating (°C)	Temperature change (°C)
butanol	20	35	15
pentanol	21	33	
hexanol	22	44	22
heptanol	21		21

i Calculate the two missing values in the table. [2]

ii Which fuel heated up the water the most? [1]

d Artem writes a conclusion for his investigation.

The temperature change was similar for all the fuels. I think 1 g of each fuel releases similar amounts of heat when they burn.

Do you agree with Artem's conclusion? Explain why, or why not. [2]

8 Part of the reactivity series is given below.

sodium	**iron**
calcium	**lead**
magnesium	**copper**
zinc	**gold**

a Use the reactivity series to predict which of the following pairs of substances will react when they are heated together. [1]

calcium and zinc oxide
iron and zinc oxide
copper and lead sulfate solution
lead and copper sulfate solution

b Write word equations for the reactions in part (a) that you predict will react. [2]

c Use the reactivity series to help you explain the following:

i Why gold is used to make jewellery. [1]

ii Why water taps are not made from calcium. [1]

iii Sodium is stored under oil. [1]

9 Name the salts made by the following pairs of substances.

a Copper oxide and hydrochloric acid. [1]

b Magnesium and sulfuric acid. [1]

c Zinc and nitric acid. [1]

10 Copy and complete the word equations below.

a calcium + water → [1]

b magnesium + oxygen → [1]

c zinc + hydrochloric acid → [1]

11 Zara wants to make zinc chloride. She adds zinc to hydrochloric acid, until a little zinc remains unreacted. Then she filters the mixture.

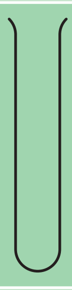
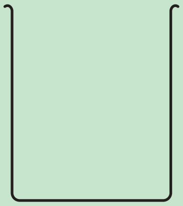
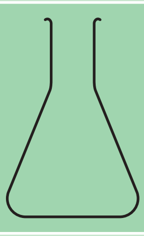
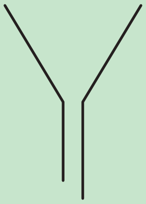
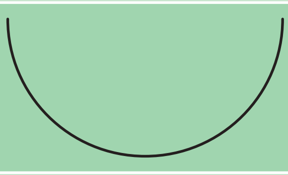
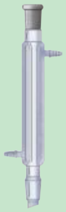
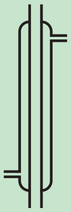
a Explain why she filters the mixture. [1]

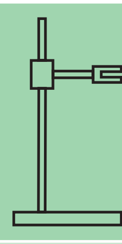
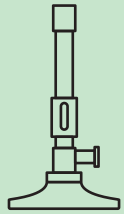
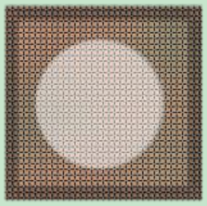
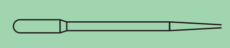
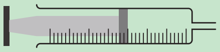
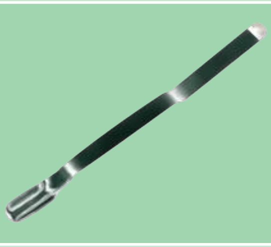
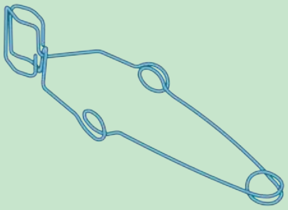
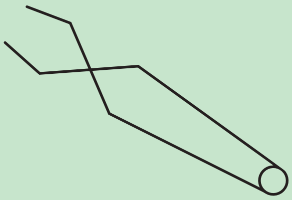
b Describe how Zara can make zinc chloride crystals from her zinc chloride solution. [2]

Reference 1

Choosing apparatus

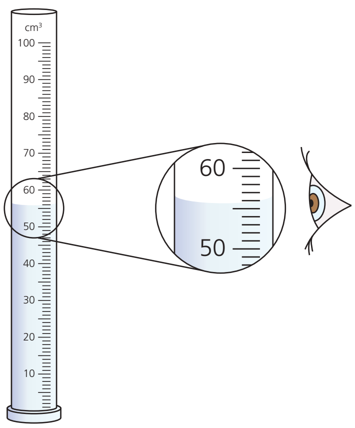
There are many different types of scientific apparatus. The table below shows what they look like, how to draw them, and what you can use them for.

Apparatus name	What it looks like	Diagram	What you can use it for
test tube			• Heating solids and liquids. • Mixing substances. • Small-scale chemical reactions.
boiling tube			• A boiling tube is a big test tube. You can use it for doing the same things as a test tube.
beaker			• Heating liquids and solutions. • Mixing substances.
conical flask			• Heating liquids and solutions. • Mixing substances.
filter funnel			• To separate solids from liquids, using filter paper.
evaporating dish			• To evaporate a liquid from a solution.
condenser			• To cool a substance in the gas state, so that it condenses to the liquid state.

stand, clamp, and boss			• To hold apparatus safely in place.
Bunsen burner			• To heat the contents of beakers or test tubes. • To heat solids.
tripod			• To support apparatus above a Bunsen burner.
gauze			• To spread out heat from a Bunsen burner. • To support apparatus such as beakers over a Bunsen burner.
pipette			• To transfer liquids or solutions from one container to another.
syringe			• To transfer liquids and solutions. • To measure volumes of liquids or solutions.
spatula			• To transfer solids from one container to another.
tongs and test tube holders			• To hold hot apparatus, or to hold a test tube in a hot flame.

Reference
2

Working accurately and safely



Using measuring apparatus accurately

You need to make accurate measurements in science practicals. You will need to choose the correct measuring instrument, and use it properly.

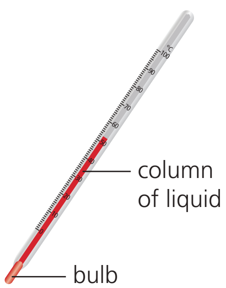
Measuring cylinder

Measuring cylinders measure volumes of liquids or solutions. A measuring cylinder is better for this job than a beaker because it measures smaller differences in volume.

To measure volume:

1. Place the measuring cylinder on a flat surface.
2. Bend down so that your eyes are level with the surface of liquid.
3. Use the scale to read the volume. You need to look at the bottom of the curved surface of the liquid. The curved surface is called the **meniscus**.

Measuring cylinders measure volume in cubic centimetres, cm^3, or millilitres, ml. One cm^3 is the same as one ml.



The different parts of a thermometer.

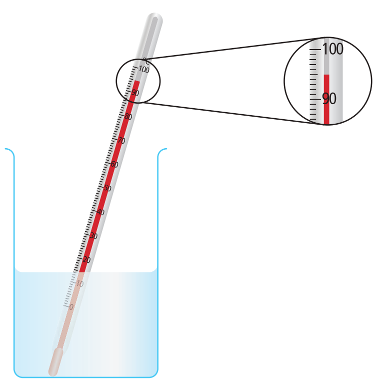
Thermometer

The diagram to the left shows an alcohol thermometer. The liquid expands when the bulb is in a hot liquid and moves up the column. The liquid contracts when the bulb is in a cold liquid.

To measure temperature:

1. Look at the scale on the thermometer. Work out the temperature difference represented by each small division.
2. Place the bulb of the thermometer in the liquid.
3. Bend down so that your eyes are level with the liquid in the thermometer.
4. Use the scale to read the temperature.

Most thermometers measure temperature in degrees Celsius, °C.



The temperature of the liquid is 95 °C.

Balance

A **balance** is used to measure mass. Sometimes you need to find the mass of something that you can only measure in a container, like liquid in a beaker. To use a balance to find the mass of liquid in a beaker:

1. Place the empty beaker on the pan. Read its mass.
2. Pour the liquid into the beaker. Read the new mass.
3. Calculate the mass of the liquid like this:

   (mass of liquid) = (mass of beaker + liquid) – (mass of beaker)

Balances normally measure mass in grams, g, or kilograms, kg.

The balance measures mass.

Working safely

Hazard symbols

Hazards are the possible dangers linked to using substances or doing experiments. Hazardous substances display **hazard symbols**. The table shows some hazard symbols. It also shows how to reduce risks from each hazard.

Hazard symbol	What it means	Reduce risks from this hazard by…
	Corrosive – The substance attacks and destroys living tissue, such as skin and eyes.	• Wearing eye protection • Avoiding contact with the skin
	Irritant – The substance is not corrosive, but will make the skin go red or form blisters.	• Wearing eye protection • Avoiding contact with the skin
	Toxic – Can cause death, for example, if it is swallowed or breathed in.	• Wearing eye protection • Wearing gloves • Wearing a mask, or using the substance in a fume cupboard
	Flammable – Catches fire easily.	• Wearing eye protection • Keeping away from flames and sparks
	Explosive – The substance may explode if it comes into contact with a flame or heat.	• Wearing eye protection • Keeping away from flames and sparks
	Dangerous to the environment – The substance may pollute the environment.	• Taking care with disposal

Other hazards

The table does not list all the hazards of doing practical work in science. You need to follow the guidance below to work safely. Always follow your teacher's safety advice, too.

- Take care not to touch hot apparatus, even if it does not look hot.
- Take care not to break glass apparatus – leave it in a safe place on the table, where it cannot roll off.
- Support apparatus safely. For example, you might need to weigh down a clamp stand if you are hanging heavy loads from the clamp.
- If you are using an electrical circuit, switch it off before making any change to the circuit.
- Remember that wires may get hot, even with a low voltage.
- Never connect wires across the terminals of a battery.
- Do not look directly at the Sun, or at a laser beam.
- **Wear eye protection** – ***whatever*** you are doing in the laboratory!

Reference 3

Recording results

A simple table

Results are easier to understand if they are in a clear table.

Write the name of the variable you change or compare in box X. If it is something you can measure, add its units.

X (units)	Y (units)

Write the name of the variable you observe or measure in box Y. If you are measuring it, add the right units.

Use one line for each test you plan to do.

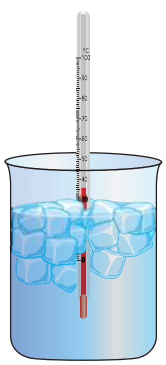
Write the names of any variables you control under the table, and add their values.

I kept these variables the same to make it a fair test:

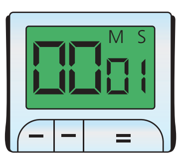
e.g. volume of water = 50 cm^3

Units

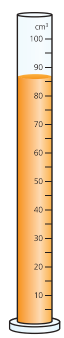
It is very important to use the correct units.



The units of **temperature** include **degrees celsius (°C)**.

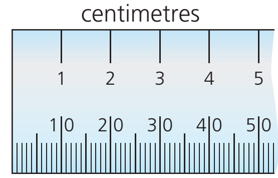


The units of **time** include **seconds (s)**, **minutes (min)**, and **hours (hr)**.



The units of **volume** include **cubic centimetres (cm^3)** and **cubic decimetres (dm^3)**.

The units of **mass** include **grams (g)**, **kilograms (kg)**, and **tonnes (t)**.



The units of **length** include **millimetres (mm)**, **centimetres (cm)**, **metres (m)**, and **kilometres (km)**.

Making results reliable, and reducing error

You should always try to repeat observations or measurements. Never rely on a single result. If repeat results are similar, they are more **reliable**. Repeating results also helps to reduce error. If the results keep changing, try to find out why. It could be a mistake, or there might be another variable you need to control.

When you collect similar measurements, you should calculate their average value.

Three students find the time it takes to draw a table. Jamil takes 75 seconds, Abiola takes 35 seconds, and Karis takes 73 seconds.

Abiola's result is **anomalous** because it is very different from the others. Jamil and Karis find out why. Abiola's table is very messy. She did not use a ruler. They decide to leave it out of the average.

$$\textbf{average time} = \frac{\textbf{sum of the measurements}}{\textbf{number of measurements}} = \frac{\textbf{75 + 73}}{\textbf{2}} = \frac{\textbf{148}}{\textbf{2}} = \textbf{74 seconds}$$

A table for repeat results

X (units)	Y (units)			
	1	2	3	average

Draw boxes for three results for each test, and an average value. If a result looks anomalous, repeat it.

A table for results that need to be calculated

Some variables can't be measured. They need to be calculated from two different results. Do all the calculations before you calculate an average value.

X (units)	Result 1 (units)	Result 2 (units)	Y (units)	Average (units)

Draw boxes for three sets of measurements, three calculated values, and an average. If a result looks anomalous, repeat it.

Reference 4

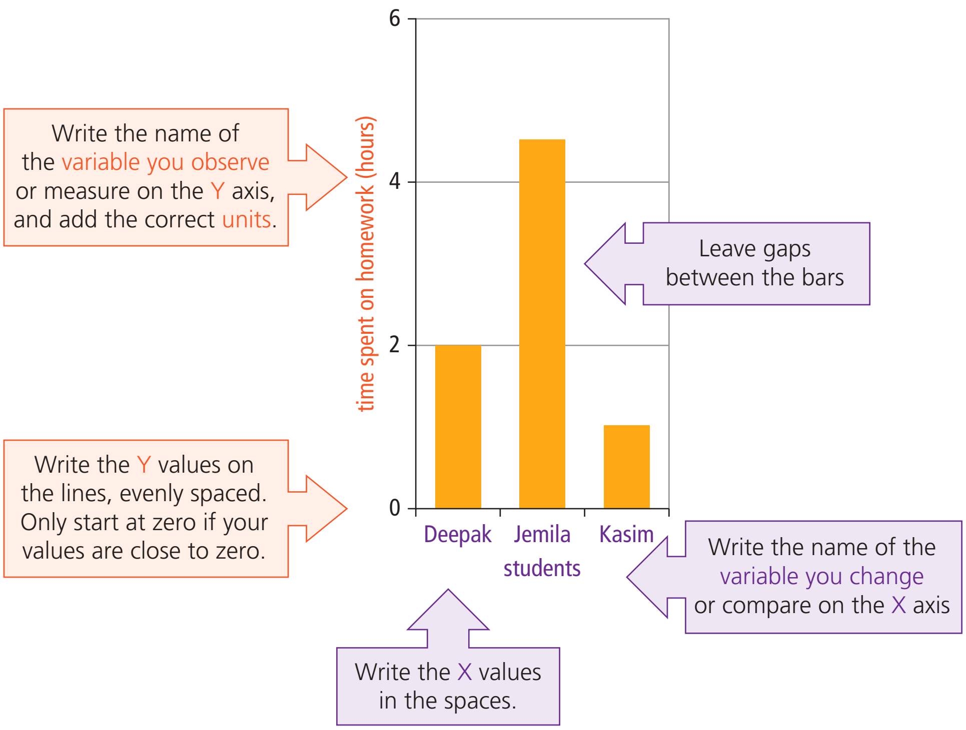
Displaying results

Drawing a bar chart

Three students timed how long they spent doing homework. The results are in the table.

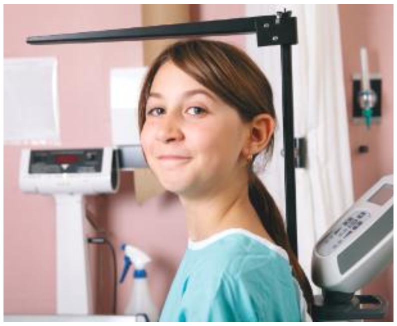
A bar chart makes results like these easier to compare.

Students	Time spent on homework (hours)
Deepak	2
Jamila	4.5
Kasim	1



Categoric or continuous

If the values of the variable you change (X) are words, then X is a **categoric** or **discrete** variable. You can only draw a bar chart for this type of variable.



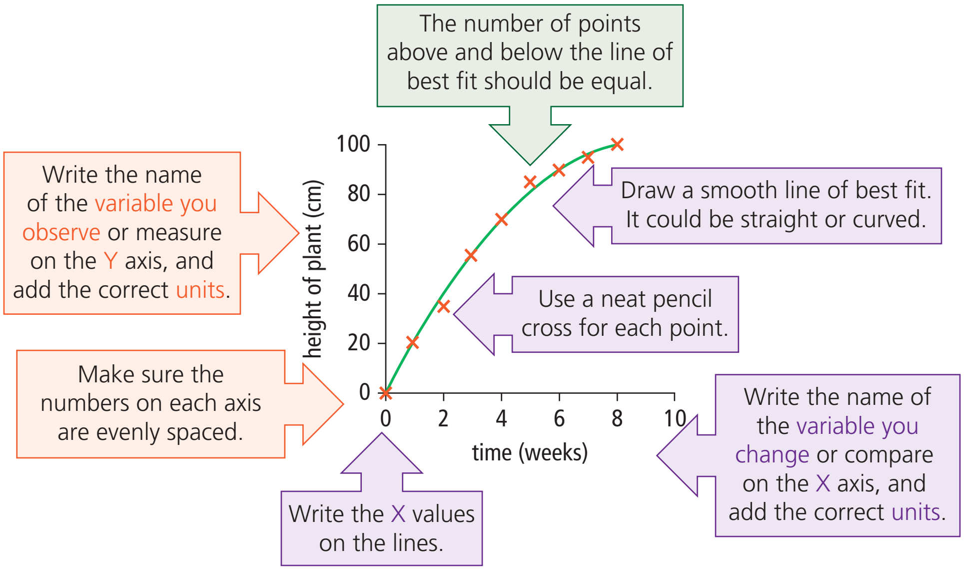
Variables like shoe size are also categoric variables. They are numbers, but there are no inbetween sizes.

Other variables are **continuous** variables. Their values can be any number. Height is a continuous variable and so is temperature.

If the variables you change and measure are both continuous variables, display the results on a line graph or scatter plot.

Drawing a line graph

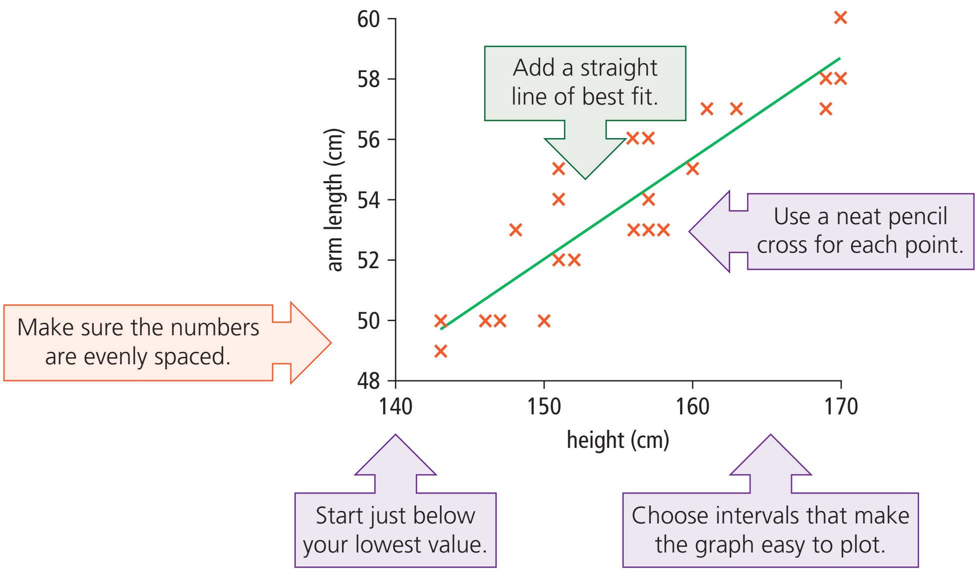
A line graph makes it easier to see the **relationship** between two continuous variables – the variable you change or compare and the variable you observe or measure.



Drawing a scatter graph

A scatter graph shows whether there is a **correlation** between two continuous variables. In the graph below, all the points lie close to a straight line. That means there is a correlation between them.

A correlation does not mean that one variable affects the other one. Something else could make them both increase or decrease at the same time.



Reference 5

Analysing results: charts and diagrams

Describe the pattern.
(e.g. A is bigger than B)

↓

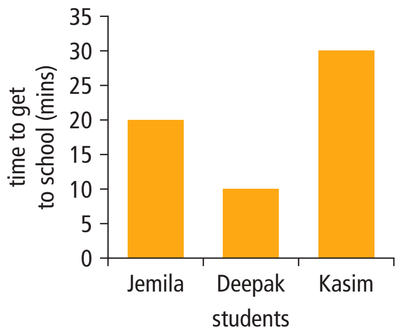
Use the numbers to compare results.
(e.g. A is three times bigger than B)

↓

Suggest a reason using scientific knowledge.
(e.g. This is because...)

Charts and diagrams help you to analyse results. They show differences between results clearly. The flow chart shows you how to analyse results.

Here is a bar chart to show how long it takes three students to get to school.



The first stage of analysing your results is to **describe the pattern**.

> "Deepak takes the shortest time to get to school. Kasim takes the longest time to get to school."

The next stage it to **use the numbers** on the *y*-axis of the bar chart to **make comparisons**.

> "Deepak takes 10 minutes to get to school, but Kasim takes 30 minutes. Kasim takes three times longer.

Finally, **suggest reasons** for any differences that you have found.

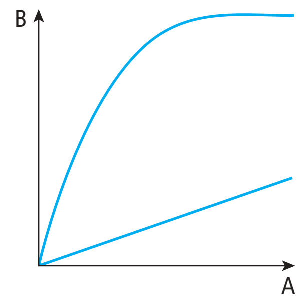
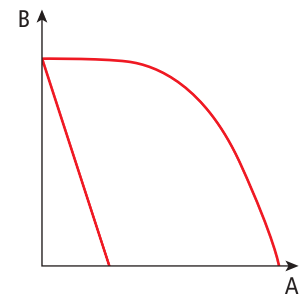
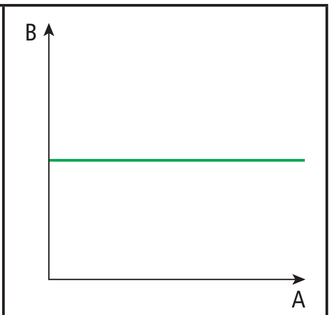
> "This could be because Kasim lives further away or because Deepak walks more quickly."

When you do an experiment, use **scientific knowledge** to explain differences between results. Here are some examples of scientific reasons.

Analysing results – line graphs

Line graphs show correlations between continuous variables. When you have plotted the points on a line graph, draw a line of best fit. Then analyse the graph. The flow chart on the right shows how to do this.

In the graphs below the line of best fit is shown, but not the points.

		
In both these graphs, if A increases then B increases.	In both these graphs, if A increases then B decreases.	If A increases B does not change.
These graphs show a **positive correlation**.	These graphs show a **negative correlation**.	This graph shows **no correlation**.

Describe the pattern by saying what happens to B as A increases. (e.g. As A increases B increases)

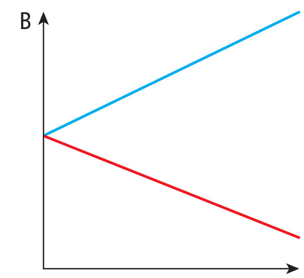
↓

Choose pairs of values to illustrate the pattern and compare them. (e.g. When A is 3, B is 2, and when A is 6 B is 4 so doubling A will double B)

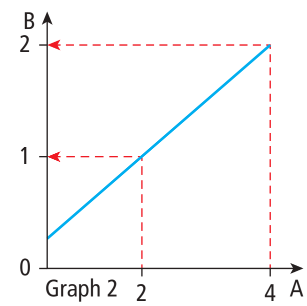
↓

Suggest a reason using scientific knowledge. (e.g. This is because...)

On some graphs the line of best fit is a straight line. You can say 'B changes by the same amount for each increase in A'. The blue line in Graph 1 shows that B increases by the same amount for each change in A. The red line shows that B decreases by the same amount for each change in A. You can choose values to illustrate this. Graph 2 on the right shows how.

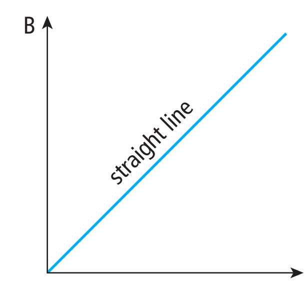


Graph 1



Graph 2

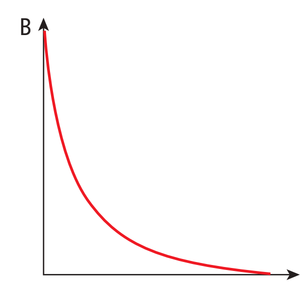
A graph with a positive correlation where the line of best fit is a straight line that *starts at zero* is a special case. In this case B is **directly proportional** to A. You can say 'if A doubles then B will also double'. (See Graph 3.) You can choose values to illustrate this.



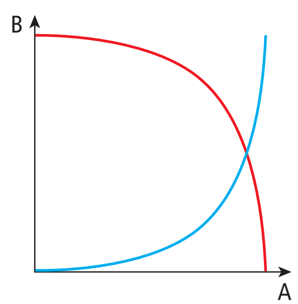
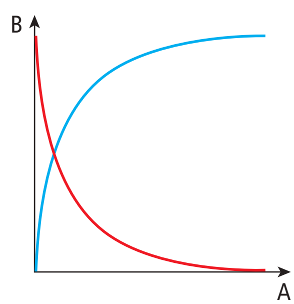
starts at zero

Graph 3

A graph that has a curved shape with a negative correlation may show that B is **inversely proportional** to A. Choose pairs of values. If you get the *same number* every time you multiply A by B then B is inversely proportional to A. This is the same as saying 'if you double A then B will halve'. (See Graph 4.) You can choose values to illustrate this.



Graph 4

	
Here B increases, or decreases as A increases BUT does so more *quickly* as A gets bigger.	Here B increases, or decreases as A increases BUT does so more *slowly* as a gets bigger.

When you have described the pattern in your results, try to use scientific knowledge to explain the pattern.

Reference
6

Detecting gases

Hydrogen gas

To find out whether a reaction in a test tube has produced hydrogen gas:

1. Collect a small quantity of gas by holding an empty test tube upside down over the top of the test tube containing the reaction mixture.
2. Place a lighted splint in the gas.
3. If the splint goes out with a squeaky pop, hydrogen gas is present.

Oxygen gas

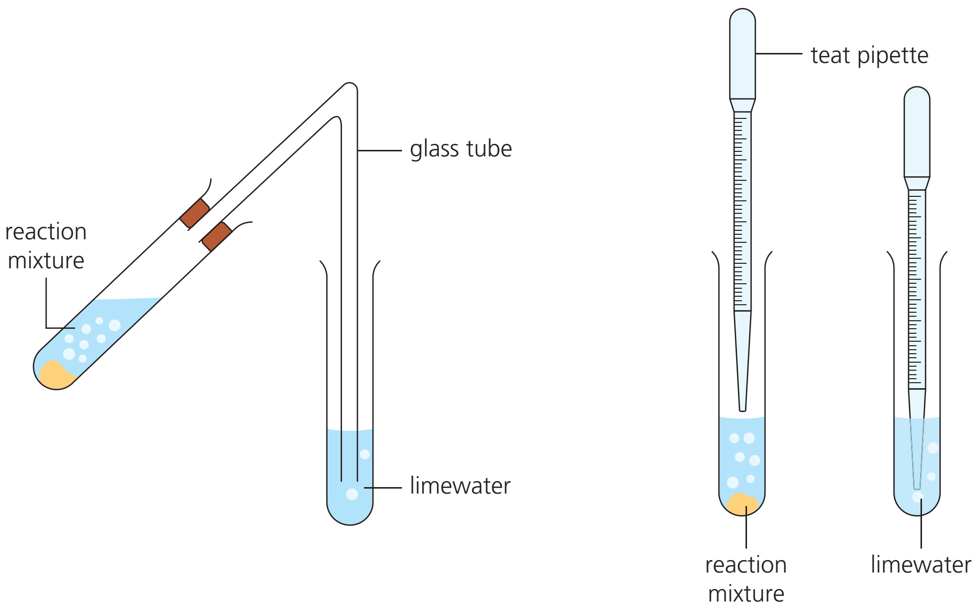
To find out whether a reaction in a test tube has produced oxygen gas:

1. Collect a small quantity of gas by holding an empty test tube upside down over the top of the test tube containing the reaction mixture.
2. Place a glowing splint in the gas.
3. If the splint relights, oxygen gas is present.

Carbon dioxide gas

To find out whether a reaction in a test tube has produced carbon dioxide gas:

- Bubble the gas through limewater solution.
- If the limewater solution turns milky or cloudy, carbon dioxide is present.



The diagrams show two ways of bubbling gases through limewater.

Reference
7

Periodic Table

The periodic table shows all of the elements in order of the number of protons they have in their nucleus – the proton number.

				1.0 H hydrogen 1													4 He helium 2
7 Li lithium 3	9 Be beryllium 4											11 B boron 5	12 C carbon 6	14 N nitrogen 7	16 O oxygen 8	19 F fluorine 9	20 Ne neon 10
23 Na sodium 11	24 Mg magnesium 12											27 Al aluminium 13	28 Si silicon 14	31 P phosphorus 15	32 S sulfur 16	35.5 Cl chlorine 17	40 Ar argon 18
39 K potassium 19	40 Ca calcium 20	45 Sc scandium 21	48 Ti titanium 22	51 V vanadium 23	52 Cr chromium 24	55 Mn manganese 25	56 Fe iron 26	59 Co cobalt 27	59 Ni nickel 28	63.5 Cu copper 29	65 Zn zinc 30	70 Ga gallium 31	73 Ge germanium 32	75 As arsenic 33	79 Se selenium 34	80 Br bromine 35	84 Kr krypton 36
85.5 Rb rubidium 37	88 Sr strontium 38	89 Y yttrium 39	91 Zr zirconium 40	93 Nb niobium 41	96 Mo molybdenum 42	(98) Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
133 Cs caesium 55	137 Ba barium 56	139 La lanthanum 57	178.5 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 Tl thallium 81	207 Pb lead 82	209 Bi bismuth 83	210 Po polonium 84	(210) At astatine 85	222 Rn radon 86
(223) Fr francium 87	(226) Ra radium 88	(227) Ac actinium 89	(261) Rf rutherfordium 104	(262) Db dubnium 105	(266) Sg seaborgium 106	(264) Bh bohrium 107	(277) Hs hassium 108	(268) Mt meitnerium 109	(271) Ds Darmstadtium 110	(272) Rg roentgenium 111							

Note: This periodic table does not include all the elements.

Glossary

Acid a solution with a pH of less than 7

Acidic a substance is acidic if its pH is less than 7

Acid rain rain that is more acidic than usual because substances such as sulfur dioxide are dissolved in it

Air pressure the force exerted by air particles when they collide with 1 m^2 of a surface

Alkali a solution with a pH of more than 7

Alkaline a solution is alkaline if its pH is more than 7

Alloy a mixture of two or more elements, at least one of which is a metal

Anomalous an odd result, or piece of data, that does not fit the pattern of results

Atom the smallest particle of an element which can exist

Balance an instrument for measuring mass

Basalt an igneous rock formed from liquid rock that cooled quickly. Its crystals are relatively small.

Base metal oxides are bases. They neutralise acids.

Beaker a container that you can use for mixing, reacting, and heating chemicals

Best-fit line a smooth line on a graph that travels through or very close to as many plotted points as possible

Biological weathering the breaking up or wearing down of a rock by the action of living things

Boil when a substance changes from the liquid state to the gas state at its boiling point

Boiling point the temperature at which a substance in the liquid state boils and changes to the gas state. Every substance has its own boiling point.

Brittle a substance is brittle if it breaks easily when you hit it with a hammer

Bunsen burner a piece of apparatus that burns gas to heat things in the laboratory

Burning a reaction in which a substance reacts quickly with oxygen and gives out light and heat. Also called combustion.

Carbonates a group of compounds which make carbon dioxide when they react with acid. Carbonates are made up of atoms of carbon, oxygen, and a metal element. There are 3 oxygen atoms for every 1 carbon atom.

Catalyst a substance which speeds up a reaction without itself being used up in the reaction

Cementation the 'gluing together' of particles of sediment by different minerals

Change of state the change that happens when a substance changes from one state to another, for example from solid to liquid or from gas to liquid

Chemical reaction an event which creates new substances and which is not easy to reverse

Chemical symbols letters which represent elements (usually one or two letters) which are understood in all languages. Each element has its own chemical symbol.

Chemical weathering the breaking up or wearing down of rocks by the action of chemicals such as those in rainwater

Chloride a compound that is made up of chlorine and one other element, for example sodium chloride, NaCl

Chromatogram a record obtained from chromatography

Chromatography a method of separating mixtures of liquids

Clay soil in clay soil, at least 40% of the rock fragments are clay

Claystone an example of a sedimentary rock

Collision when a particle bumps into another particle, or the inside of its container

Combustion a burning reaction, in which a substance reacts quickly with oxygen and gives out light and heat

Compaction when sediments are squashed together to make new rocks by the weight of layers above

Compound a substance made up of atoms of two or more elements chemically joined together

Concentrated a solution that contains a lot of solute dissolved in very little solvent

Concentration the amount of a substance that is dissolved in a certain volume of a solution

Condense when a substance changes from the gas state to the liquid state at the boiling point of the substance or below

Continuous variable a variable which can have any value within a range, for example time, temperature, length, mass

Contracts gets smaller

Correlation a link between two variables

Corrosion a reaction that happens on the surface of a metal when the metal reacts with substances from the air or water around it. Corrosion reactions happen slowly.

Corrosive a corrosive substance destroys living tissue

Creative thinking thinking in a new way

Crude oil a thick black liquid formed underground, or under the sea, from the remains of plants and animals that died millions of years ago. Crude oil is used to make fuels, such as petrol and diesel, and many plastics.

Crust the outer layer of the Earth. It is made up of different types of rock, and is thinner than the other layers of the Earth.

Crystal a substance in the solid state with its atoms arranged in a regular pattern, for example salt and diamond

Data measurements taken from an investigation

Decanting carefully pouring off a liquid from a mixture of the liquid with a solid, in which the solid has settled to the bottom; or pouring off the top liquid from two liquids that have settled one on top of the other.

Density the mass of a substance in a certain volume. A substance with a high density feels heavy for its size.

Deposition the settling of sediments that have moved away from their original rock

Diffusion the spreading out and mixing of particles from areas with many particles to areas with fewer particles

Discrete variable a variable whose values are words, or whose values can only have certain numerical values

Diesel a fuel separated from crude oil

Dilute a solution that contains very little solvent dissolved in a lot of solvent

Dissolve when a substance (the solute) mixes with a liquid (the solvent) to make a solution

Displacement reaction a reaction in which a more reactive metal displaces a less reactive metal from a compound of the less reactive metal

Distillation a method of separating a solvent from a solution, for example water from salty water

Ductile a material is ductile if it can be pulled into wires

Electric balance an instrument for measuring mass that is powered by electricity

Electron a sub-atomic particle that moves around the outer parts of an atom. It has a single negative charge. Its relative mass is 1/1840.

Element a substance consisting of atoms of only one type. It cannot be split into new substances.

Empirical question a question that can be answered scientifically, by collecting evidence and using creative thought

Endothermic change a change in which energy is taken in from the surroundings.

Energy levels electrons in atoms occupy energy levels. Energy levels are also called shells, or orbits.

Erosion the processes of weathering and transportation together make up erosion

Evaporation when a substance changes from the liquid state to the gas state. Evaporation can happen at any temperature.

Evidence observations or measurements that support a scientific explanation

Exothermic change a change in which energy is released to the surroundings.

Expand get bigger

Explanation a scientific idea that explains evidence and which scientists have developed using creative thought

Fair test an investigation in which all the variables are kept constant except the variable which the investigator changes

Filter a way of removing pieces of solid that are mixed with a liquid or solution by pouring through filter paper

Filtration separating pieces of solid from a mixture with a liquid or solution

Fluid a substance that has no fixed shape and that flows to fill a container or space

Fossil the remains or traces of a plant or animal that lived many years ago

Fossil fuels fuels made from the remains of animals and plants that died millions of years ago, for example coal, oil, and natural gas

Formula (plural formulae) a formula uses symbols and numbers to show the relative number of atoms of each element in a compound. For example, the formula of water is H_2O. This shows that water is made up of atoms of hydrogen and oxygen, strongly joined together. In a sample of water, there are two hydrogen atoms for every one oxygen atom.

Fractional distillation heating a liquid mixture to separate it into fractions with different boiling points

Freeze when a substance changes from the liquid state to the solid state

Freezing point the temperature at which a substance changes from the liquid state to the solid state. Each substance has its own freezing point.

Fuel a store of energy which burns to release useful heat, for example coal and diesel

Gas a fluid with no fixed volume that takes the shape of its container

Gas pressure the force exerted by gas particles when they collide with 1 m^2 of a surface

Geologist a scientist who studies the origin, structure, and composition of the Earth

Global warming the gradual increase in the Earth's average surface temperature

Gneiss an example of a metamorphic rock

Granite an igneous rock formed from liquid rock that cooled slowly. Its crystals are relatively large.

Greenhouse gases gases that contribute to climate change, for example carbon dioxide

Group the elements in one vertical column of the periodic table

Group 1 elements the elements in the left vertical column of the periodic table

Group 2 elements the elements in the vertical column that is second from the left of the periodic table

Group 7 elements the elements in the vertical column that is second from the right of the periodic table. They are also called the halogens.

Halogens the elements in the vertical column that is second from the right of the periodic table. They are also called the group 7 elements.

Hard a material is hard if it is difficult to scratch

Hazard a possible source of danger

Hazard symbols warning symbols on chemicals that show what harm they might cause if not handled properly

Hummus decayed plant and animal matter in the soil

Hydroxide a compound made up of a metal, hydrogen, and oxygen.

Index fossil a fossil type that identifies the geological time period in which a rock was formed. Every time period has its own index fossil.

Inner core the solid iron and nickel at the centre of Earth

Insoluble a substance that does not dissolve in a solvent

Inverse correlation a link between two variables in which when one variable increases, the other variable decreases

Igneous rock rock made when liquid rock (called magma below the surface of the Earth, and lava above the surface of the Earth) cooled and solidified

Isotope atoms of the same element which have different numbers of neutrons are called isotopes

Joule (J) the unit of energy

Kilogram unit of mass

Kilojoule (kJ) 1000 joules

Lava hot liquid rock that is on – or above – the surface of the Earth

Limestone an example of a type of sedimentary rock. It is mainly calcium carbonate

Liquid a fluid with a fixed volume that takes the shape of its container

Litmus indicator an indicator which tells you if a substance is acidic or alkaline. If a substance is alkaline, it makes red litmus become blue. If a substance is acidic, it makes blue litmus paper red.

Loam in a loam soil the rock fragments are 40% sand, 40% silt, and 20% clay

Magma hot liquid rock that is beneath the Earth's surface

Malleable a material is malleable if it can be hammered into shape without cracking

Mantle the layer of the Earth that is beneath the crust. It is solid but can flow very slowly. It goes down almost halfway to the centre of the Earth.

Marble a metamorphic rock formed from limestone

Mass the amount of matter in something

Materials the different types of matter that things are made of

Matter stuff that takes up space and has mass

Measuring cylinder a piece of apparatus that measures volumes of liquids or solutions

Melt when a substances changes from the solid state to the liquid state

Melting point the temperature at which a substance changes from the solid to liquid state. Every substance has its own melting point.

Meniscus the surface of a liquid

Metalloid an element with properties that are between those of metals and non-metals

Metals elements which are good conductors of heat and electricity. Most elements are metals. They are to the left of the stepped line on the periodic table.

Metamorphic rock a type of rock formed by the action of heat and/or pressure on sedimentary or igneous rock

Minerals substances that occur naturally. They are usually made up of crystals.

Mixture a mixture contains two or more elements or compounds mixed together. The substances in a mixture are not chemically joined together.

Molecule a particle of a substance made from two or more atoms that are strongly joined together

Mudstone a type of sedimentary rock

Natural polymer a polymer that exists naturally, often made by plants or animals

Neutral a substance or solution with a pH of 7 which is neither acidic nor alkaline

Neutralise to add acid or alkali to a solution to make a solution of pH 7

Neutralisation the process of making a solution neutral

Non-metals elements that are not metals. They do not conduct electricity. They are to the right of the stepped line of the periodic table.

Non-porous a non-porous material does not have small gaps containing gases or liquids. Water cannot soak into a porous material.

Nucleon number the number of protons and neutrons in the nucleus of an atom. It is also called mass number.

Nucleus (plural **nuclei)** the central part of an atom. Most of the mass of an atom is in its nucleus. The nuclei of all elements are made up of protons and neutrons, except for the nuclei of most hydrogen atoms which are made up of one proton only.

Neutron a sub-atomic particle found in the nucleus of an atom. It has no electric charge. Its relative mass is 1, the same as the mass of a proton.

Observations the results of looking carefully at something and noticing properties or changes

Oil a fossil fuel formed from sea creatures over millions of years

Orbits electrons in atoms occupy orbits. They are also called energy levels, or shells.

Ore a rock that contains natural minerals from which useful substances, for example metals, can be extracted

Outer core the liquid iron and nickel between the Earth's mantle and inner core

Oxide a compound of oxygen with another element

Palaeontologists scientists that study fossils and use evidence from them – and creative thinking – to understand the history of life on Earth

Particle theory a theory that uses ideas about particles to explain how matter behaves

Particles tiny pieces of matter from which everything is made

Period a horizontal row of the periodic table

Periodic table an arrangement of all the elements in order of increasing number of protons (proton number). In the periodic table, the elements are grouped with those that have similar properties.

pH a way of measuring how acidic or alkaline a solution is

pH scale the range of levels of acidity and alkalinity

Physical weathering the breaking up or wearing down of rocks, for example, by the effects of changing temperature

Polymer a substance with large molecules made up of atoms joined together in long chains

Porous a porous material has small gaps which may contain gases or liquids. Water can soak into a porous material.

Predict suggest what you think will happen

Prediction a suggestion of what will happen

Preliminary work observations or measurements done at the start of an investigation to work out appropriate values for control variables

Primary data data collected directly for a particular investigation

Products the new substances that are made in a chemical reaction

Property a characteristic of a substance; how it behaves

Proton a tiny sub-atomic particle with a positive charge. Protons are found in the nuclei of atoms. The relative mass of a proton is 1, the same as that of a neutron.

Proton number the number of protons in the nucleus of an atom

Radiometric dating this uses the natural decay of particles in a rock to measure the age of a rock

Range the difference between the biggest value and the smallest value in a series of data

Rate of reaction how fast a reaction is. The faster a reaction, the greater its rate.

Reactants the starting materials, or substances that react together, in a chemical reaction

Reactivity series a list of metals placed in order of their reactivity

Risk the chance of damage or injury from a hazard

Rock cycle the rock cycle explains how rocks change and are recycled into new rocks over millions of years

Rusting the corrosion reaction of iron. Oxygen and water are needed for iron to rust. The product of the reaction – rust – is hydrated iron oxide.

Sacrificial protection putting a more reactive metal in contact with a less reactive one so that the more reactive metal corrodes. The more reactive metal is sacrificed to protect the less reactive one.

Salt a compound in which the hydrogen atom of an acid has been replaced by a metal atom. Salts may be formed in neutralisation reactions or in reactions of acids with metals or metal oxides.

Sandstone an example of a type of sedimentary rock

Sandy soil in sandy soil, most of the rock fragments are sand

Saturated solution a solution in which no more solute can dissolve

Scientific journal a collection of papers, written by scientists, which describe their work and which have been carefully checked by other scientists

Scientific model an idea that explains observations, and that you can use to make predictions. A scientific model of an object or phenomenon is simpler than the real thing.

Secondary source a source such as a book or the Internet which provides evidence or data that you have not collected yourself

Sedimentary (rock) rock made from sediments joined together by pressure or chemicals

Sedimentation the settling of solid particles that were mixed with a liquid

Sediments pieces of matter which have settled to the bottom of a liquid

Semiconductor a material is a semi-conductor if it conducts electricity less well than conductors, but better than insulators

Semi-metal an element with properties that are between those of metals and non-metals

Shells electrons in atoms occupy shells. Shells are also called energy levels, or orbits

Slate a metamorphic rock made from mudstone

Solid a state of matter in which the substance has a fixed shape and volume

Solubility the maximum mass of solute that can dissolve in 100 g of solvent

Soluble a substance is soluble in a solvent if it can dissolve in that solvent

Solute a substance which dissolves in a solvent to make a solution

Solution a mixture of solvent and solute, in which the solute has dissolved.

Solvent in a solution, the liquid in which the solute is dissolved

Sonorous a material is sonorous if it makes a ringing sound when hit

States of matter most substances can exist as a solid, a liquid, and a gas. These are the states of matter.

Stirring rod a rod, usually made from glass, that is used to stir chemicals

Strata the layers of sedimentary rocks and soils that have built up over time

Strong a material is strong if a large force is needed to break it

Sub-atomic particles the particles that make up an atom, including protons, neutrons, and electrons

Sublimation when a substance changes from the solid state directly to the gas state

Sublime when a substance changes from the solid state directly to the gas state

Sulfate a compound that includes atoms of the elements sulfur and oxygen. There are four oxygen atoms for every one sulfur atom.

Symbol equation an equation in which the reactants and products are represented by their formulae. It gives the relative amounts of the substances in the reaction, and their states.

Synthetic polymer a polymer made by people and machines in factories or science laboratories

Temperature a measure of how hot something is

Thermite reaction the displacement reaction of iron oxide with aluminium. The products are iron and aluminium oxide. The reaction releases a great amount of energy as heat and light.

Thermometer an instrument you can use to measure temperature

Transportation the processes by which sediments of rock that have been removed from their original rock by weathering are moved away from the original rock

Universal Indicator (UI) a solution that changes colour to show the pH of the solution it is mixed with

Uplift uplift happens when huge forces from inside the Earth push rocks upwards. The process makes mountains.

Variable a quantity which can change in an investigation, for example time, temperature, length, mass

Vulcanologist a scientist who studies volcanoes

Weathering weathering breaks up all types of rock into smaller pieces, called sediments

Word equation a word equation summarises a chemical reaction in words. It shows the reactants and products. The arrow means 'react to make'.

Index

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Complete Chemistry for Cambridge Secondary 1

Author
Phillipa Gardom Hulme

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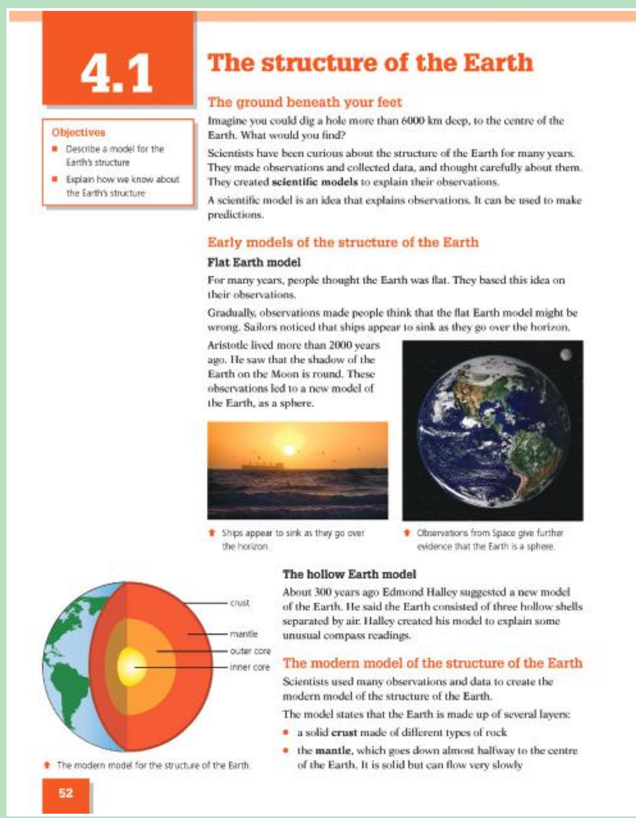
4.1

The structure of the Earth

Objectives

- Describe a model for the Earth's structure
- Explain how we know about the Earth's structure

The ground beneath your feet

Imagine you could dig a hole more than 6000 km deep, to the centre of the Earth. What would you find?

Scientists have been curious about the structure of the Earth for many years. They made observations and collected data, and thought carefully about them. They created **scientific models** to explain their observations.

A scientific model is an idea that explains observations. It can be used to make predictions.

Early models of the structure of the Earth

Flat Earth model

For many years, people thought the Earth was flat. They based this idea on their observations.

Gradually, observations made people think that the flat Earth model might be wrong. Sailors noticed that ships appear to sink as they go over the horizon.

Aristotle lived more than 2000 years ago. He saw that the shadow of the Earth on the Moon is round. These observations led to a new model of the Earth, as a sphere.

Ships appear to sink as they go over the horizon.

Observations from Space give further evidence that the Earth is a sphere.

The hollow Earth model

About 300 years ago Edmond Halley suggested a new model of the Earth. He said the Earth consisted of three hollow shells separated by air. Halley created his model to explain some unusual compass readings.

The modern model of the structure of the Earth

Scientists used many observations and data to create the modern model of the structure of the Earth.

The model states that the Earth is made up of several layers:

- a solid **crust** made of different types of rock
- the **mantle**, which goes down almost halfway to the centre of the Earth. It is solid but can flow very slowly

crust
mantle
outer core
inner core

The modern model for the structure of the Earth.

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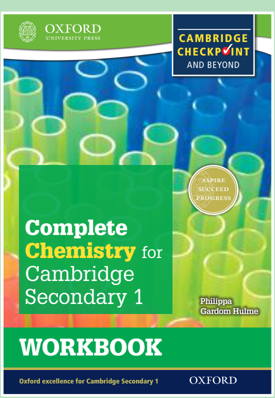

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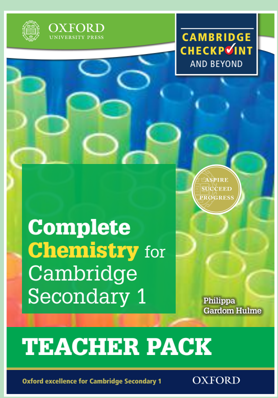

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